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ABSTRACTS



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Abstracts

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ECVP

The European Conference on Visual Perception is an annual event. Previous conferences took place in:

1978 Marburg (D)	1986 Bad Nauheim (D)	1994 Eindhoven (NL)
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1985 Peñíscola (E)	1993 Edinburgh (GB)	2001 Kuşadası (TR)

ECVP '02 Abstract

SUNDAY

SYMPOSIUM

MARR'S *VISION*—20 YEARS AFTER

► *Vision*—20 years after

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I discuss three aspects of Marr's seminal contributions to the study of vision. The first is his definition of distinct levels of analysis in vision theory, the second is the framework of the main visual representations, and the third is his studies of specific visual processes.

Marr proposed a conceptual distinction between three levels of analysis: computational theory, algorithm, and mechanism. Though not entirely new, Marr's work gave them the clearest articulation, and pointed out their importance to the study of vision and brain science in general. Stressing the distinction between brain mechanisms in vision and the computations they support had a strong influence in the experimental neurosciences, but to a lesser degree in computational vision and theoretical brain science. In computational vision there has been a decreased emphasis of the study of brain mechanisms, and in theoretical brain science there has been an increased emphasis of the study and modeling of brain mechanisms on their own. The conceptual separation of levels was challenged over the last 20 years by some developments in connectionism and neural-network modeling, where the three levels, in particular mechanism and algorithm, are difficult to separate. An insight that emerged from these directions is the essential role of learning that was not an integral part of Marr's formulation.

Marr viewed the process of vision primarily as the construction of three levels of representations: the primal sketch, the 2.5-D sketch, and a final 3-D object-centred representation. The primal sketch is an intriguing notion that received relatively little attention in both computational vision and empirical studies. In higher-level vision and object recognition, Marr's ideas have been a major driving force in the first half of the last 20-year period, but more recently attractive alternatives based more directly on 2-D appearance have emerged.

In the study of specific visual processes, such as stereo vision and edge detection, Marr's classical work had an enduring effect. It is remarkable and thought-provoking that in some basic areas Marr's original work is still close to the current state of the art.

► **The primal sketch revisited: locating and representing edges in human vision via Gaussian-derivative filtering**

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Marr's work offered guidelines on how to investigate vision (the theory – algorithm – implementation distinction), as well as specific proposals on how vision is done. Many of the latter have inevitably been superseded, but the approach was inspirational and remains so. Marr saw the computational study of vision as tightly linked to psychophysics and neurophysiology, but the last twenty years have seen some weakening of that integration. Because feature detection is a key stage in early human vision, we have returned to basic questions about representation of edges at coarse and fine scales. We describe an explicit model in the spirit of the primal sketch, but tightly constrained by psychophysical data. Results from two tasks (location-marking and blur-matching) point strongly to the central role played by second-derivative operators, as proposed by Marr and Hildreth. Edge location and blur are evaluated by finding the location and scale of the Gaussian-derivative 'template' that best matches the second-derivative profile ('signature') of the edge. The system is scale-invariant, and accurately predicts blur-matching data for a wide variety of 1-D and 2-D images. By finding the best-fitting scale, it implements a form of local scale selection and circumvents the knotty problem of integrating filter outputs across scales.

[Supported by BBSRC and the Wellcome Trust.]

- **Structure, surfaces and shape: superficial and in-depth influences of Marr on visual physiology**
A J Parker (Laboratory of Physiology, University of Oxford, Parks Road, Oxford OX1 3PT, UK; e-mail: andrew.parker@physiol.ox.ac.uk)

Marr's legacy to the understanding of vision has influenced visual neuroscience in two main ways. On the grand scale, by connecting insights about the complex structure of the visual environment with conjectures about the operation of the visual nervous system, Marr offered a sound theoretical basis for visual neuroscience, which is closely linked to classical Darwinian thinking about adaptive fitness. On a more specific, fine-grain scale, Marr's work has a continuing influence on the psychophysics and physiology of visual shape and surfaces. I review some of the ways in which interactions between modelling and experimental work have sustained the progress of neurophysiological research, with examples from the study of binocular depth and other cues to 3-D shape. The long-lasting appeal and influence of Marr's work arises from its role as an exemplar of a complete theoretical position that addresses the complex demands placed upon visual processing.

[Supported by the Wellcome Trust.]

- **Marr's 'Vision' in retrospect**

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Marr wrote at a marked divide in the history of 'Vision', so much is clearly visible in retrospect. I find it next to impossible to disentangle the many threads that immediately come to mind, though: the take-off of 'machine vision' (half a dozen related terms might be substituted), the technological discontinuity that changed psychophysics and neurophysiology, the explosion of formal tools (information theory, genericity in geometry, fractals, ...). Were novel concepts in psychology generated by such changes or do we witness a genuine instance of metabletics? In retrospect, the changes are so obvious and sudden (on the scale of development of Western science) that they indeed invite close attention. When you try to pick your dozen trendsetting figures for these events, is Marr among them? I try to sort out the threads my way, paying special attention to the interrelations of the various disciplines.

- **Why did Marr's program fail? A Gibsonian view**

W H Warren (Department of Cognitive and Linguistic Sciences, Box 1978, Brown University, Providence, RI 02912, USA; e-mail: Bill_Warren@brown.edu)

Not long after Marr's book appeared, his program of computational vision was superseded by neural network and Bayesian approaches. Why did Marr's program fail? I argue that at the computational level (i) the goal of vision was too general, and (ii) assumptions about the world were too specific. The presumed goal of vision—to recover a common 3-D model of a Euclidean world—was too strong, rendering the problem of perception underdetermined. This necessitated simplifying assumptions about the physical world in order to 'make the process run' but which did not reflect natural constraints. The resulting solutions were not computationally robust, nor did they empirically capture biological vision. Importantly, human perception is both worse (non-Euclidean) and better (more robust) than the algorithms. For weaker task-specific goals, perception need not be underdetermined. The field urgently needs empirical analyses of (i) the specific tasks of biological vision—what Gibson called a description of the environment to be perceived; (ii) the natural constraints that serve as grantors of information—ecological physics; and (iii) the optical information that, under these constraints, specifies environmental properties—ecological optics. With Gibson's guidance, we may be able to rehabilitate Marr and hold out for a theory of perception.

- **Advancing from 'vision' to 'seeing'**

W Richards (Artificial Intelligence Laboratory, Massachusetts Institute of Technology, NE43-767, Cambridge, MA 02139, USA; e-mail: wrichards@mit.edu)

Twenty years later, we comfortably use Marr's levels of representation to categorise efforts toward understanding vision. Our students use his book as an introduction, and are guided by its examples. Whenever vision can be cast as a problem of inference, Marr's approach has no equal. Consequently, striking advances have been made with machine vision systems having specific objectives in controlled contexts. Our understanding of human vision has not fared as well, however. One reason lies in a narrow interpretation of Marr's 1982 formulation that focuses on problems such as object recognition, surface shape, or scene structure. For Marr, the recovery of scene properties from images was "the easy part" of understanding vision—just a first step. The more difficult challenge is to understand how image information should be interpreted or "explained", for example as events or actions. For this task, more powerful semantic models are needed. In 1970, Marr offered the beginnings of a relevant framework in his paper on "Theory for

cerebral neocortex”. The key was a “fundamental hypothesis” that semantic categorisations are based on redundant structure in the world—ie “natural modes”. Our interpretations of sense data may be guided by this intrinsic knowledge, whose form we are only beginning to understand.

THE PERCEPTION LECTURE

➡ **Lotze and the theory of local signs**

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The concept of local sign is similar to that of ‘positional information’ in developmental biology. Rudolf Hermann Lotze (1817–1881) put forward the theory of local signs to explain how positional information was transmitted from the retina to the motor system. Under the influence of Kant, he thought that local signs could not, in themselves, be spatial. He therefore postulated that they were qualitative properties of the nerve fibres themselves. Later, he modified this theory in favour of the notion that local signs were related to the sense of effort associated with eye movements.

Positional information is required to make eye movements or hand-pointing movements to briefly flashed stimuli in the dark. A key issue is whether this kind of positional information is also used in spatial judgments of angle and spatial extent, where relational rather than absolute decisions are made. The earliest and highest-precision kind of visual geometry seems to involve the extraction of vectors between pairs of points. Various second-stage filtering models of angle and spatial acuity have been proposed, but their unattractive feature is that they lead to an explosion in the number of detectors required. It is tempting to follow Lotze and to suppose that the mechanisms encoding magnitudes and directions are identical to those for the programming of eye movements. An attractive feature of this theory is that vector averaging could account for a variety of geometrical illusions. The evidence is reviewed.

MONDAY

ORAL PRESENTATIONS

BRAIN IMAGING

◆ Representation of perceived contrast in primary visual cortex

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It has been previously shown that V1 activity closely predicts human and monkey contrast-discrimination behaviour, but there is only sparse evidence that V1 also represents perceived contrast. In the present study, we manipulated physical contrast and perceived contrast independently by using the orientation tuning of lateral masking, and generated stimuli that matched either physically or perceptually. We correlated early transient evoked potentials and evoked magnetic fields with contrast-judgment psychophysics in order to assess whether the physical stimulus properties (physical contrast) or perceptual properties (perceived contrast) are better predicted by V1 activity. Results indicate that: (i) perceived contrast is reduced for target stimuli flashed into parallel as compared to orthogonal surrounds; (ii) the amplitudes of early (100 ms) and late (150 ms) striate components are strongly reduced for parallel compared to orthogonal stimuli of the same physical contrast; (iii) when gratings are perceived to have the same contrast, response amplitudes of both early striate components are very similar, especially the second (late) striate component N150. These results show that contrast is already strongly rescaled in V1 from a representation based on physical contrast to a percept-based representation and that perception is best correlated with a later, integrative feedback stage of processing.

◆ Are there speed-dependent fMRI responses in human V1?

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In a recent study with an optic-flow stimulus, the fMRI activation of human visual area V1 was found to decrease linearly with speed, consistent with the fact that speed-sensitive cells in V1 have been shown to be tuned to low speeds. However, speed-sensitive mechanisms are not necessarily needed to explain this apparent speed dependence. Since fMRI responses to visual stimuli depend strongly on contrast, a simple temporal-summation-based decrease in perceived contrast could explain the finding. To test this hypothesis, we used stimuli in which the perceived contrast did not change with speed, namely drifting sine-wave gratings with a fixed temporal frequency. We found that the tuning in V1 was bandpass, in agreement with the results of Singh et al (2000 *Neuroimage* 12 550–564) for spatial-frequency dependence of V1 responses. They used a temporal frequency different from ours, and when we plotted their data and our data together as a function of spatial frequency, the curves were almost overlapped. However, as a function of speed, their data were shifted with respect to ours along the speed axis. This suggests that, when the effects of contrast are removed, it is spatial frequency and not speed that defines the magnitude of V1 activation.

◆ Human V1 and V2 compared with fMRI

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What is the nature of the information transformation that occurs between V1 and V2? Receptive fields (RFs) are larger in V2, in humans (Smith et al, 2001 *Cerebral Cortex* 11 1182–1190) as in other primates. Is there simply a biased projection from V1 to V2 that favours neurons sensitive to low spatial frequencies, as has been suggested? Or does the increase in RF size in V2 reflect integration of information across space? These alternatives have quite different implications for the function of V2. Human observers were presented with a stimulus consisting of a slowly expanding, centrally fixated ring of bandpass spatially filtered 2-D dynamic noise. This was intended to isolate a subset of neurons with a particular spatial-frequency sensitivity. Functional MRI (1.5T GE LX/Nvi) was used to estimate the average RF size of this neuron subset in human V1 and V2, on the basis of the duration of the response elicited as the stimulus passes through the receptive fields of the neurons in each voxel. If information is passed from V1 to V2 with no major change in RF properties (ie V2 just contains a higher proportion of low-spatial-frequency

neurons), then a given bandpass-filtered stimulus should activate neurons with the same RF size in both areas. The size difference we have previously observed with broadband stimuli should therefore disappear.

In both V1 and V2, mean estimated RF size was found to decrease as the stimulus spatial frequency was increased, confirming that neurons in both areas are tuned for spatial frequency. Receptive fields were larger in V2 than V1, even with bandpass-filtered stimuli. This suggests that receptive fields in human V2 are generated by integrating the outputs of a group of V1 neurons that have a common spatial-frequency sensitivity but slightly different RF locations. [Supported by The Wellcome Trust.]

◆ **Neural responses to motion and form in humans: a VEP study**

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Displaying a succession of independent Glass patterns (dipoles oriented radially, concentrically, or linearly) conveys a strong sense of global motion in that direction, even though the stimulus itself contains no coherent motion (Ross et al, 2000 *Current Biology* **10** 679–682). VEP responses were recorded in adult humans to successions of independent Glass patterns and compared with VEP responses to global motion. To elicit a VEP response, the stimuli alternated between coherently arranged dipoles, randomly arranged dipoles, coherently arranged dipoles, and randomly arranged dipoles. The proportion of dipoles arranged in a coherent spatial structure (signal) was varied from trial to trial to evaluate the signal-to-noise sensitivity of the VEP response. This response decreased quickly with the number of coherently arranged dipoles, extrapolating to the psychophysical threshold. Signal-to-noise sensitivity for independent Glass patterns was also higher (double) than for global motion, indicating a weaker mechanism subserving perception of motion conveyed solely by form information. There were also significant VEP responses in recordings where independent Glass patterns were alternated with coherently moving random dots matched for velocity and direction of motion, suggesting the presence of two distinct mechanisms.

◆ **Topography of the chromatic pattern-onset VEP**

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The chromatic pattern-onset VEP has been used as a sensitive and objective measure of neural integrity in both congenital and acquired visual losses. It also has been used to characterise development, maturation, and aging of the chromatic visual pathways. Here we extended this technique to include multifocal recordings that provide topographic measures of chromatic responses. This extension includes a systematic exploration of three-dimensional colour space and a comparison with pattern reversal responses. Multifocal VEP recordings were made with the VERIS system that extracts topographic VEPs with a pseudorandom stimulus sequence. Stimuli were chromatic patterns in which colours were modulated along different axes in the MBDKL colour space. Patterns were presented in an onset–offset temporal mode. Our data indicate that, as with achromatic pattern-onset responses, the character of the waveforms depends on topographic location. In particular, there is an inversion and cancellation of the waveform in the upper visual field. The general character of the waveform shows smaller changes within the lower visual field. For stimuli with chromatic contributions, pattern onsets produced more reliable and consistent waveforms, whereas for stimuli with large luminance contributions pattern-reversal stimuli were superior.

[Supported by NIA grants to MAC and JSW.]

LIGHTNESS AND BRIGHTNESS

◆ **Observers correct perceived albedo for perceived orientation when stereo disparity cues are available**

L T Maloney, H Boyaci (Department of Psychology and Center for Neural Science, New York University, 6 Washington Place, 8th Floor, New York, NY 10003, USA; e-mail: ltm@cns.nyu.edu)

When a scene contains a punctate source, the amount of light that reaches the eye from a patch on a matte gray surface depends on both patch albedo and patch orientation. We examined whether the human visual system actively discounts perceived orientation in estimating perceived

albedo. Seven scenes were rendered with identical punctate + diffuse lighting models from two slightly different viewpoints, creating a stereo pair. Each contained a collection of specular and matte objects chosen to allow the observer to determine the direction from a test patch to a distant punctate source. The scenes differed in the orientation of a test patch to light rays radiating from the punctate source. The observer viewed the scenes in a Wheatstone stereoscope and, on each trial, performed two tasks. He or she first estimated the orientation of a gray rectangle by adjusting a superimposed gradient probe, and then matched the lightness of the patch to a standard gray scale. Three naïve observers made these two judgments 20 times for each of the scenes in random order. Observers' estimates of orientation and lightness were found to be highly reliable and covaried as would be expected if the observers were discounting perceived albedo for perceived orientation.

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◆ **Phenomenology and visual metaphors in the representation of light sources and luminosity**

D Zavagno (NEC Research Institute, 4 Independence Way, Princeton, NJ 08540, USA; e-mail: dzavagno@research.nj.nec.com)

Light is a fundamental aspect both of visual perception and of visual arts, but only few rare, yet important, contributions have been made in both fields to understand its peculiarities. In the present work I address some of the issues concerning the perception and representation of light by tracing a line through history of art in order to connect salient moments of representation of light sources. The purpose is to show not only how certain graphic ideas have been used in symbolic terms and were transposed from one civilization to another, or even adopted by different civilizations with apparently no contact, but also to point out that many of those graphic ideas are somewhat less than the phenomenal experience itself, yet also somewhat more than a visual metaphor. Finally, along with the presentation of some work in progress, I show how to produce compelling illusions of luminosity in pictorial displays.

◆ **Grouping of non-adjacent illumination frameworks**

S Zdravković, A L Gilchrist (Department of Psychology, Rutgers University, 101 Warren Street, Newark, NJ 07102, USA; e-mail: suncica@psychology.rutgers.edu)

Our previous findings (2001 *Perception* **30** Supplement, 18) suggested that parts of the scene which are under the same illumination level could group together even when they are non-adjacent. However, the basis of this grouping remained unspecified. Is it based on a common (i) luminance range, (ii) average luminance, or (iii) highest luminance? When five squares suspended in mid-air are presented in a spotlight, their lightness range is compressed, but adding additional squares to this group reduces the compression. We tested whether a non-adjacent 25-square Mondrian presented in a similar spotlight can have the same effect (reducing compression). The answer is yes, when the two displays have the same highest luminance. Additional experiments show that this grouping effect weakens with (a) increased lateral separation between the displays, (b) increased depth separation, and (c) reduced difference between the illumination of the room and that of the two displays.

◆ **Two types of simultaneous lightness contrast**

A D Logvinenko, D A Ross (School of Psychology, DKB, Queen's University of Belfast, Belfast BT9 5BP, Northern Ireland, UK; e-mail: a.logvinenko@qub.ac.uk)

Simultaneous lightness contrast is often used to refer to a variety of different visual phenomena, eg Adelson's tile illusion and grating induction. We present evidence that the former is a pictorial illusion: generated by the same mechanisms as lightness constancy. It is pictorial in that a 3-D wall of blocks, forming the same retinal pattern as Adelson's tile picture, brings forth no illusion (Logvinenko et al, 2002 *Perception* **31** 73–82). To ascertain how Adelson's illusion is related to lightness constancy we presented a picture of the wall of blocks covered by a striped overhead transparency. The retinal pattern was nearly the same as Adelson's but the diamonds in the alternating stripes had different luminances. Nevertheless, twenty observers perceived almost no difference between them in lightness. Moreover, both Adelson's lightness illusion and lightness constancy were found to be very close in strength. On the contrary, being much smaller in magnitude, grating induction does not disappear when implemented in 3-D objects. As shown by Kane and Logvinenko (2002 *Perception* **31** this Supplement) grating induction can be observed from 3-D real cylinders. It proves that grating induction and Adelson's illusion are different in their nature. Thus, they cannot be reduced to a unique explanatory mechanism.

◆ **Lightness or brightness? Kanizsa's paradox**

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Kanizsa (1954 *Archivio di Psicologia* **15** 251–264) demonstrated a paradoxical effect in the domain of surface colour. The demonstration consists of two parts: (i) two grays compared in a contrast configuration show the classical simultaneous lightness contrast effect, while the same grays in an assimilation configuration undergo an assimilation effect; (ii) when comparing the contrast configurations to those of assimilation, paradoxically, the gray judged darker in the contrast configuration is perceived more similar to the gray judged lighter in the assimilation configuration, and a symmetrical similarity is observed for the other two grays. According to Kanizsa, in this type of comparison, lightness and brightness are confounded. In this research, four experimental displays derived from Helson's contrast and assimilation configurations were judged separately on the continuum of lightness. A 2×2 design has been used: direction of physical contrast (increments or decrements) and physical contrast (high or low inducer luminance). Contrast has been found for increments and no effect for decrements in the assimilation configurations, while contrast configurations show contrast for both increments and decrements. In conclusion, lightness matches elicit contrast effects also in assimilation configurations; this fact and the simultaneous presence of both contrast and assimilation configurations, seem to be crucial factors for the paradox to occur.

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VISUAL DEFICITS

◆ **Are size distortion effects in hemispatial neglect reflected in grasping and/or eye-movement impairments?**

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A proportion of patients with hemispatial neglect subjectively devalue the sizes of objects presented in their contralateral hemisphere. When presented with two identical horizontally arranged objects they report that they are different in size, the left object appearing subjectively shorter than the right one. This symptom has been linked to the chronic attentional bias such patients have; however, it has also been suggested that the effect is simply due to hemianopia or the combination of neglect and hemianopia. In the first experiment reported here we show that this effect is (a) unrelated to eye movements—such patients scan stimuli in the same way as controls, despite the fact that they perceive the left object as smaller, and (b) unrelated to hemianopia, as even patients without hemianopia show the effect. We also show that, when neglect patients are asked to grasp for objects in the contralesional space, their maximum grip aperture is no different from that of control subjects. We therefore propose that the effect reflects a representational/computational distortion of horizontal extent rather than an impairment mediated by either hemianopia or a chronic (overt) attentional bias.

[All authors would like to thank the Wellcome Trust for financial support.]

◆ **Training-induced patterns of visual-field recovery: changes of objective and subjective visual-field size in brain-lesioned patients**

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Topographical patterns of functional recovery over six months of visual restitution training were observed, and changes of objective and subjective visual-field size were compared.

Nineteen patients with post-genicular lesions of the visual system performed visual restitution training. During pre-training and post-training baseline measurements, objective visual-field size was determined by perimetric tests, and subjective scotoma size was specified in a standardised chart of the right and left eye. Correlations between objective and subjective visual-field size and changes in both variables over the treatment period were determined.

Even before training, subjective visual-field size correlated with perimetric measurements. Stimulus detection in objective visual-field tests increased over the training period, while subjective

tive defect size decreased. Form and size of the scotoma were adequately represented in most patients, with foveal defects being perceived as larger than more peripheral parts of the scotoma. Training-induced improvement could also be recognised in patients' drawings. Thus, visual restitution training increases intact visual-field size in objective visual-field tests but also affects the subjective representation of the defect. Both measures reflect the architecture of the visual system because patterns of recovery follow the laws of the cortical magnification factor.

◆ **Visuo-spatial channels of processing in blindsight**

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Blindsight is the visual discrimination ability within the field defect of a cortically blind patient. This ability may be in the absence of any awareness of stimulus presentation (type I) or may accompany some awareness (type II), but still in the absence of any 'seeing'. We aimed to develop a standardised protocol for screening for blindsight in a large number of cortically blind subjects to address the prevalence and characteristics of residual vision. Detection of suprathreshold gratings in a two-alternative forced-choice paradigm provides a criterion-free measure of spatial processing within the field defect. With this technique, the presence of a bandpass spatial channel has been reported previously in one blindsight subject. We have applied the same methodology to study ten cortically blind subjects with V1 lesions. We have demonstrated the presence of blindsight in eight of the ten subjects studied. The spatial channels mediating blindsight appear to have bandpass frequency response characteristics in two subjects and low-pass in six subjects. The higher cutoff frequencies in all cases were below 4 cycles deg^{-1} . The lower cutoff frequency of the bandpass channel was approximately 0.5 cycle deg^{-1} . The low spatial-frequency tuning of the spatial vision may reflect subcortical mediation.

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◆ **Spatial vision in cortical blindness: a pupillometric investigation**

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Despite advances in the investigation of residual vision following cortical blindness by psychophysical methods, the need for indirect and objective testing methods is clear. Pupillary responses to spatial gratings (PGR) with space-averaged luminance equal to the background, have been reported as an objective measure of spatial processing in normal observers. Their presence has previously been reported in one cortically blind subject. We investigated whether such findings can be generalised and whether pupillometry can screen for spatial processing within the field defect of ten cortically blind subjects. Pupil responses to static, vertical sine-wave gratings (spatial frequencies 0.5–7 cycles deg^{-1}) subtending 10 deg (viewing distance 760 mm) with space-averaged luminance equal to the background, were obtained for sighted and blind-field presentations. We have demonstrated the presence of PGRs to a range of spatial frequencies in some of the cortically blind subjects. Blind-field response amplitudes were attenuated with peak sensitivities shifted to lower spatial frequencies compared to the sighted field. All subjects with clear blind-field pupil responses also showed blindsight when tested psychophysically, suggesting that pupillometry may be a useful technique for the detection of residual spatial channels and screening for blindsight.

[Supported by the Chief Scientist Office, Scottish Executive, Grant CZB/4/30.]

◆ **Perceptual and memory deficits of dyslexics**

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Previously, we found that contrast detection of temporally modulated stimuli by dyslexics is impaired only when observers are required to 'retain-and-compare' between sequentially presented stimuli. We now ask whether similar deficits characterise tasks with stationary stimuli. Using both auditory (tones) and visual (sinusoidal gratings) stimuli, we found that dyslexics are significantly impaired on sequential frequency discrimination in both modalities. We further compared visual spatial-frequency discrimination under two conditions. In the simultaneous condition, observers were asked whether the stripes were denser in the upper or lower half of the screen. In the serial one, the choice was between the first and second intervals. Consistent with our previous findings, the majority of dyslexics were impaired on the serial, retain-and-compare condition. A significantly smaller group effect was found for the simultaneous condition. Dividing the dyslexics into two subgroups based on their auditory frequency discrimination, we found dyslexics with

poor auditory abilities were impaired under both visual conditions. The other dyslexics were impaired only when retain-and-compare was required. These results imply that dyslexics with poor psychoacoustic performance suffer from broad visual and auditory perceptual impairments. The perceptual deficits of the other dyslexics are revealed only when memory is required.

EYE MOVEMENTS

◆ **Optimal retinal stimulation for intrasaccadic motion perception of a static grating**

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We previously showed that a static low spatial-frequency (SF) grating briefly flashed during a saccade is perceived as moving against the saccade direction. We have further investigated this intrasaccadic perception to make sure that it is mainly determined by motion cues. Static vertical 100% contrast gratings lasting 19 ms were flashed during voluntary horizontal saccades (amplitude = 6 deg, mean duration = 40 ms, mean peak velocity = 280 deg s⁻¹). Observers reported whether motion was perceived or not. After off-line analysis of eye movements, probability of motion perception was plotted against time relative to saccade onset. Three different SFs were used. Motion perception is maximal with an SF of 0.2 cycle deg⁻¹, decreases with lower SF (0.04 cycle deg⁻¹), and is abolished with higher SF (1.8 cycles deg⁻¹), suggesting that the range of intrasaccadic retinal temporal frequencies is the main determinant of the percept. For low SFs, optimal motion perception occurs when the grating is displayed during the accelerating phase of the saccade, ie when retinal temporal frequency of the grating increases (from 0 Hz to 40 Hz with the 0.2 cycle deg⁻¹ SF). This suggests that reliable motion signals result from a very fast temporal integration giving more weight to the latest temporal frequencies.

◆ **Coherent motion pops out during smooth pursuit**

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Stimulus motion is a prominent feature that is used by the visual system to segment figure from ground and perceptually bind widely separated objects. Tracking eye movements (ie pursuit) can be influenced by perceptual-grouping processes. We have examined the subjects' ability to detect small amounts of coherent motion in random-dot kinematograms (RDKs) during pursuit. We compared performance on tests of coherent-motion perception while subjects fixated a stationary spot or while they tracked a moving target. The results indicate that smooth pursuit can improve subjects' ability to detect the presence of coherent motion. We propose that an efference copy of the eye-movement signal can enhance the ability of the visual system to detect correlations between sparsely placed targets among noisy distractors.

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◆ **The contribution of eye movement to the detection of motion-in-depth**

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Extra-retinal information about eye position is theoretically highly useful for scaling disparities and interpreting 3-D motions. Yet, the oft-cited paper by Regan et al (1986 *Investigative Ophthalmology & Visual Science* 27 584–597) suggests that changes in ocular convergence alone are not an adequate stimulus for perceiving motion-in-depth. We consider this further by investigating the role that eye movements play in detecting motion towards or away from an observer. Motion detection was examined under a 2IFC, constant stimuli protocol for conditions with or without tracking eye movements. Observers detected small displacements in depth (d_{\min}) under three conditions: absolute motion (no reference marks visible); relative motion-fixation (observers fixate a cross); relative motion-tracking (observers track the moving dot). Speed of motion was varied from 0.25–2 min of arc s⁻¹ to alter the rate of change of vergence demand. Detection thresholds for absolute motion were higher than for relative motion, although differences were attenuated at higher speeds. Relative motion-tracking thresholds were higher than in fixation conditions. Observers are able to detect motion defined only by changes of absolute disparity. However, the addition of eye movements to relative motion has a detrimental influence on detection performance. This is surprising because the retinal motions in each relative motion condition should be identical.

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◆ **Classification images for saccadic targeting and perceptual decisions during search**

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Previous results have shown that, for matched processing times, the accuracy of the first saccade and the perceptual decision in visual-search detection tasks are, on average, nearly the same [Beutter et al, 2000 *Investigative Ophthalmology & Visual Science* **41**(4) S424]. In addition, saccadic and perceptual decisions to identical external-noise samples are correlated, suggesting similar underlying filters for both processes (Beutter et al, 2001 *Vision Science*). Here, we use the classification-image technique to estimate the underlying filters mediating saccadic targeting, and compare it to those mediating perceptual decisions during search for a target (bright Gaussian) among four distractors (dim Gaussian). We recorded eye movements and perceptual responses of observers under two conditions. In a long condition (up to 4 s), observers made saccades to search the display and we defined the 5AFC saccadic decision as the element location closest to the endpoint of the first saccade. In a short condition (durations to match saccadic processing time), central fixation was required, and we recorded the 5AFC perceptual decision. Noise samples corresponding to incorrectly chosen locations were used to estimate classification images and allow for a direct comparison of the underlying filters mediating saccadic and perceptual decisions during search.

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◆ **Flashers are distracting—flashed distractors, motion interference, and smooth pursuit initiation**

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We have shown previously that a single stationary distractor presented synchronously with, and at the mirror image position to, a smooth pursuit (SP) target, modifies the initiation of SP. This effect could be due to interference in V5 as motion-sensitive cells respond transiently to stationary stimuli. We have now examined the effect of a flashed distractor appearing 150 ms or 500 ms before an SP target. Subjects were exposed to step-ramp tasks in which the target ($0.3 \text{ deg} \times 0.3 \text{ deg}$) appeared 5 deg to either the left or right of fixation and moved at 14 deg s^{-1} back through the centre of the display. The distractor ($1.5 \text{ deg} \times 1.5 \text{ deg}$) was flashed (duration 100 ms), either at the eventual target position (ipsilateral) or on the opposite side of fixation (contralateral). Horizontal eye movement was recorded by infrared oculography and SP latency was measured off-line. Ipsilateral distractors, flashed 150 ms before the SP target, significantly increased SP latency ($p < 0.001$); contralateral distractors slightly decreased latency. Both caused small, non-significant decreases in latency when flashed 500 ms before the SP target. These results are consistent with distractors flashed at 150 ms causing transient responses in V5 which interfere with the motion processing necessary for the initiation of SP. Clearly, however, this effect declines rapidly.

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SYMPOSIA

VISUAL ARTS AND PERCEPTION

► **Artful visions**

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Visual artists and visual scientists are often concerned with examining the same phenomena, but the methods they adopt differ radically. The scientist rarefies and isolates phenomena to control them in the laboratory, whereas the artist embraces complexity and manipulates the phenomena intuitively. The differences in method have resulted in divergent vocabularies for describing similar effects, and the two approaches can appear more disparate than their phenomenal commonality would suggest. This is evident in the illustrations accompanying texts on vision. It could be argued that, prior to computer graphics, visual scientists have not represented adequately the subject matter of their own enquiry; this want was supplied by visual artists. Not only have artists provided more engaging examples of visual phenomena, but they have also enhanced their range in ways that are scientifically novel. Examples of the contributions that visual art has made to visual science are drawn from Leonardo to Ludwig Wilding. Influences in the reverse direction are also discussed.

► **Visually driven pleasure**

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I argue that human pleasure derives from episodes (which are best thought of as sequences of emotion-producing events), not events or things. Because of this re-focusing of the notion of pleasure on episodes, the role of attractiveness in pleasure is to draw us into an episode that may turn out to be pleasurable. This holds true of any episode, regardless of whether it involves art. Pleasurable episodes probably do not consist only of positive emotions. I conceive of art as a social institution whose purpose is to provide humans with an encapsulated context for obtaining pleasure more predictably than provided by one's life. Some such contexts are focused on vision, but even those that are not probably involve visual imagery. If this conception is heuristically valuable, it gives rise to a difficult research problem for visual art: how can a static object produce episodes involving sequences of emotions?

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► **Eyeware: pictures in action**

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Pictures, according to the predominant conception of them, replicate perceptual experiences, specifically visual experiences. While many pictures do have this effect, many others do not. Some pictures show us scenes we could not experience with the naked eye. Some serve to direct action and thus may not represent scenes at all. We should not confuse one important effect of pictures for the nature of pictures; pictures that do not replicate experiences prompt us to rethink what pictures are, how they relate to vision, and why they are valuable.

► **Designing visually rich, nearly random textures**

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In real life, we deal with visually rich scenes, containing edges at all orientations, and maintain a sharp perception even when moving the head and the eyes. Being interested in stereo vision, I sought to design camouflaging textures containing real edges at all orientations, first by computer, then manually. In the manual procedure, the starting point is either a set of photographs (for instance, of barks) or a manually produced first-generation texture. Then patches are cut zigzagging and assembled into successive generations of textures. Various objects were covered with textures, and photographed from two viewpoints. Although their shape was concealed in ordinary monocular viewing, some information could be retrieved under the conditions of 'monocular stereoscopy' (Claparede effect). One aesthetic criterion in the design of the textures was their capacity to suggest imaginary scenes. Small areas of a texture often suggest a scene, but, when the areas are assembled, the suggestive power is lost, and the statistical properties of the texture then dominate. However, introducing symmetry (as in the Rorschach test), meaningful scenes emerge again. The presence of contrast variations at different scales, a proper balance between homogeneity and granularity, and the absence of extended edges—straight or curved—are some of the factors which favour the formation of rich scenes extending far from the axis of symmetry.

► **Evidence against the idea that artists of the Renaissance used optical projection devices**

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There has been widespread dissemination of the ideas of artist David Hockney and physicist Charles Falco that optical projection was used by artists not only in the 17th and 18th centuries but earlier, during the Renaissance. In the absence of documentation of the existence of such devices, these authors rely on fragmentary evidence from the pictures themselves. However, this evidence does not withstand careful examination. The use of optics is implausible for many reasons, but perspective reconstruction provides the most geometric refutation. The claims require that the optical projection was performed in local regions, predicting that the perspective would be locally accurate but globally inconsistent. Perspective reconstruction of the Renaissance pictures used to support the claims reveals the opposite. The perspective vanishing points are locally incoherent but (often) globally consistent. Such a pattern of errors reveals that Renaissance artists did not use optical projection methods, and moreover that they rarely employed more than one or two of the rules of perspective.

COLOUR, FORM, AND MOTION

► What you can do with colour vision

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It is frequently argued that trichromatic colour vision has evolved to enable monkeys (and later humans) to detect ripe fruit amongst green foliage. However, it would be even better for survival if the fruit could not only be seen, but also be picked for eating. Thus I studied how well colour is suited to drive the motor system for pointing to objects defined exclusively by colour. Small coloured disks, equiluminous with a uniform gray background, were displayed briefly on a CRT touchscreen. The subjects' task was to point as precisely as possible to the location of the disk on the screen. Shutter goggles were used to blank the subjects' field of view as soon as they started moving their index finger away from its resting position. Subjects were equally precise in pointing to disks defined by luminance and colour. This held for red, green, blue, and yellow objects, and irrespectively of whether or not the subjects could see their hand while pointing. No significant differences were found for the subjects' reaction times or movement times, so the results are not due to a speed–accuracy tradeoff. The results show that colour signals drive the motor system for pointing behaviour as effectively as luminance signals.

► Colour vision facilitates intrinsic-image segmentation

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In natural scenes, variations in colour over space tend to have a material origin, whereas luminance variations can have either a material or illumination origin. Illumination-based luminance variations include achromatic transparency, shadows, highlights, and shading. We provide a number of demonstrations showing that when chromatic and luminance variations are spatially uncorrelated, the chromatic variations tend to be perceived as material whereas the luminance variations are perceived as illumination. First, the addition of colour contrast to parts of displays containing multiple, overlapping, achromatic transparencies produces marked changes in perceived figure–ground organisation, in keeping with the colour = material, uncorrelated luminance = illumination distinction. Second, we show that the addition of colour contrast to one of the components of a luminance plaid induces illusory shape-from-shading in the orthogonal plaid component. Psychophysical experiments with the colour-induced shape-from-shading effect show that its magnitude depends primarily on colour contrast, and not luminance contrast in the inducer component, suggesting that the colour contrast plays an independent role that is high-level in origin. Taken together, these findings reinforce the importance of colour vision in helping to segment the image into its illumination and material components, or 'intrinsic images'.

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► Temporal chromatic aberration: Why the motion of red – green equiluminous gratings is detected by the luminance system

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There is a growing body of evidence to question the functionality of one of the most commonly used stimuli in colour-motion research, the equiluminous chromatic grating. We describe our recent masking experiments using drifting chromatic or luminance gratings as test stimuli, presented in chromatic or luminance masking noise (spatially 1-D, temporally dynamic). We find that motion thresholds (direction discrimination) for equiluminous red–green gratings are masked by luminance noise, whereas detection thresholds are masked by chromatic noise. Our results indicate that luminance processes are determining red–green motion thresholds, while chromatic processes determine detection. The generation of luminance signals in the chromatic stimuli, which we term temporal chromatic aberration, occurs over the complete temporal range tested (0.5 Hz–9 Hz), with no low temporal frequency at which it can be eliminated. We also report that temporal chromatic aberration is specific to the red–green system and is not found in the S-cone opponent pathway. We suggest that temporal chromatic aberration arises from colour-specific temporal delays at a retinal level, as already described in the literature. Our results imply that previous data on the motion of red–green equiluminous gratings could have been based on luminance not chromatic thresholds. Hence genuine chromatic motion may be more impoverished than previously thought.

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► **Equiluminance, sensitive calibration, three-systems theory, and equiluminous chromatic motion perception**

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Because cones occupy somewhat random positions on the retina, when a moving red–green grating has been calibrated for equiluminance, it remains locally imperfect. However, net global luminance motion can be made zero by causing oppositely directed local imperfections to perfectly cancel (Lu et al, 1999 *Proceedings of the National Academy of Sciences of the USA* **96** 8289–8294). To produce such ‘pure’ equiluminous chromatic motion stimuli, every candidate stimulus must be individually calibrated by highly sensitive procedures [Anstis and Cavanagh, 1983, in *Colour Vision* Eds J Mollon, T L Sharpe (New York: Academic Press); Lu and Sperling, 2001 *Vision Research* **41** 2355–2374]. We find that ‘pure’ equiluminous motion stimuli activate only the third-order (saliency-based) motion system (Lu and Sperling, 2001 *Journal of the Optical Society of America A* **18** 2331–2370). We predict (and find) that varying only the chromatic saturation (and thereby the saliency) of the green stripes of rapidly moving equiluminous red–green gratings generates a full gamut of motion percepts from compelling smooth motion to complete motion standstill (Lu et al, 1999 *Proceedings of the National Academy of Sciences of the USA* **96** 15374–15379). Taken together, our many results imply that equiluminous chromatic motion is not computed by specialised chromatic motion mechanisms within colour pathways, but by the third-order motion system at a brain level where binocular inputs of form, colour, depth, and texture are simultaneously available, and where selective attention can exert a major influence (Blaser et al, 1999 *Proceedings of the National Academy of Sciences of the USA* **96** 11681–11686).

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► **Motion of colour stimuli: position-based but velocity friendly**

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The nature of colour contribution to motion perception has been controversial for many years. To gain a fresh perspective on this question, we have examined the smooth pursuit of drifting, equiluminous colour stimuli. Pursuit is quite good, on a par in all respects with pursuit of luminance grating of equivalent contrast, even when the motion path is unpredictable. The velocities of retinal slip during pursuit are quite low, well below the velocity threshold for the colour stimuli, implying that velocity errors cannot be guiding the pursuit for colour. The position errors of the retinal slip are, however, often above the position thresholds, suggesting that position information is a possible candidate for guiding pursuit. A pursuit initiation task showed that, just after an initial saccade to land on the drifting colour target, pursuit velocity was quite well matched to the target velocity even though velocity was varied randomly from trial to trial. We concluded that attentive tracking of the target prior to the acquisition saccade produced a velocity estimate. We suggest that even though the motion perception for the low-velocity colour stimulus is based on position tracking, as opposed to a Reichardt-like computation, the end result is a velocity estimate.

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ORAL PRESENTATIONS

VISUAL ARTS

◆ **The moon illusion in perspective drawings**

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The moon illusion is the apparent enlargement of the low moon or sun compared to higher in the sky. This illusion appears in works of art, which often contain abnormally large celestial bodies even at high elevations. Most pictures are fanciful, or follow conventions other than linear perspective. If perspective is broadly maintained, pictures can provide a measure of the illusion. Examples are shown of known scenes, where the artist’s representation is compared with a photograph. The sketch by Gillies of the village of Temple shows the February sun at an elevation of 18°, and enlarged by a factor of two compared to the midground—the same enlargement as other background objects. The painting by Eardley *Catterline in Winter* shows the afternoon sun enlarged by a factor of 2–3 compared to background objects. These estimates are within the range of other experimental measures of the illusion. Drawings of moons added by children

to photocopies of a real scene showed a large illusion in young children, reducing to the adult level by about age 9 years. [Ross and Plug, 2002 *The Mystery of the Moon Illusion* (Oxford: Oxford University Press).]

◆ **Looking at Op Art**

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In the history of visual arts we witness repeated attempts to represent features going beyond the inherently two-dimensional nature of a painting, namely depth and motion. In the works of 'Op Artists' we can experience vivid dynamic illusions in static pictures composed from simple black-and-white patterns. The variety and possible causes of these flicker and motion percepts have been the topic of extended scientific debates, with explanations ranging from retinal to cortical mechanisms. Because an important role has been attributed to eye movements, we started measuring the gaze stability of observers viewing Bridget Riley's painting *Fall*, and in a control experiment coarse checkerboard patterns or a blank field. Extensive analysis of the data from one observer shows that gaze is kept within the target region, but at the same time exhibits slow fluctuations and small and medium-sized horizontal saccades. The frequency of these rapid eye movements increases during the stimulation, and is clearly reduced for the control condition. Comparative observations from a number of subjects indicate a considerable variability of gaze stability, but a general occurrence of rapid small eye movements. Theoretical considerations indicate that such image displacements generate patterns of motion signals in a motion detector network, which may suggest a simple but sufficient explanation for the illusion.

◆ **The colours of grey: achromatic engravings before the invention of photography**

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What does it mean to see the world in black and white? In the 1920s, when movies displayed a grey world, was it true that no 'colours' were actually seen? Did every object seen in those projections appear grey in the same way? The answer is obviously "no". People in those glorious days were seeing a world full of light, shadows, and objects of different lightness. But the marvels of a grey world have not always been so richly displayed. Before the invention of photography, the depiction of the world in black and white had to face some technical and perceptual challenges. We studied the technical and perceptual constraints that XVth–XVIIIth century engravers had to face in order to transduce colours into shades of grey. An indeterminacy principle is considered, according to which artists had to prefer the representation of some object or scene features rather than others (brightness versus lightness). The reasons for this lay between the kind of grey scale technically available and the kind of information used in the construction of 3-D scenes. With the invention of photography and new printing solutions, artists had at their disposal a continuous grey scale which mostly nullifies the indeterminacy principle.

◆ **Liking what we see**

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Shapes have an aesthetic value even in the absence of meaning. This observation underlay the move to abstraction in 20th century art. It also raises the question why some shapes are more attractive than others. One possibility is that we find more pleasing forms that are more closely tuned to the properties of our visual system. An example of differential tuning is the oblique effect in orientation perception: horizontal and vertical lines have privileged access, predicting that they should also be preferred. The effect of rotating Mondrian's paintings on their aesthetic appeal was examined, controlling for frame orientation by using paintings with either oblique or horizontal/vertical frames. There was a preference for pictures when their component lines were horizontal/vertical rather than oblique and, independently of this, for the original orientation, perhaps because rotation changes the balance of the painting as well as the orientation of component lines. There was no preference for either frame orientation, but there was an interaction between frame orientation and component orientation, resulting in a preference for paintings where the components were parallel to the frame. A follow-up study analysing a representative sample of paintings found a greater use of horizontal/vertical contours in a wide range of styles.

◆ **Measuring the threshold for beauty**

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Beauty may be in the eye of the beholder, as Spinoza said, but so is the colour red. Could the methods of colour science be adapted to study beauty? We did just that to decisively test various theories for what makes particular paintings (Rothko, Ingres, etc) beautiful to particular observers. Viewing the painting through a variable-contrast reduction screen (like fog), the observer uses method of adjustment to find his or her threshold for 'receiving pleasure from this painting right now' (one definition of beauty). We also measure thresholds for other criteria, relevant to the theory being tested, eg seeing certain edges or textures. The rank order of the thresholds proves that certain features are either unnecessary or insufficient for beauty. Thus aesthetic judgments, including beauty, are just as susceptible as colour percepts to precise measurement and strong conclusions.

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COLOUR

◆ **Colour appearance variations associated with photopigment opsin genotypes**

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Investigations of colour appearance and colour cognition typically generalise the construct of neural trivariance when modeling higher-order colour sensation. Molecular-genetics research has shown that individuals can express more than three retinal photoreceptor classes, with each class tuned to a different spectral response profile. We examined the influence of additional retinal cone classes on colour sensation by assessing the colour experience of individuals possessing multiple classes of photopigment opsin genes as identified through polymerase chain reaction (PCR) genetic assays. Using a task in which subjects delineate spectra, we find variation in colour perception across groups of dichromats, trichromats, and individuals with photopigment opsin gene polymorphisms. The results provide further insight into the constraints photopigment opsin genes impose on colour sensation. Implications for cognitive models of colour-appearance phenomenology are discussed.

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◆ **Lines of constant hue do not always converge on grey**

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Current theories of colour vision assume the existence of a uniquely defined neutral point in chromaticity space. It is generally thought that this point satisfies several criteria simultaneously. One of these criteria is that it is perceived as achromatic. A further criterion shared by most theories is the structural assumption that lines of constant hue converge on the neutral point. The basic assumption that these two criteria coincide is clearly true for isolated spots of light presented in darkness, and it is usually taken for granted that this coincidence generalises to more complex visual stimuli. We show that this is not the case. Our experiments with simple equiluminant infield-surround stimuli revealed that the point in chromaticity space which appears grey is clearly different from the point on which lines of constant hue converge. This apparently paradoxical finding is incompatible with traditional three-dimensional conceptions of perceptual colour space in terms of hue, saturation, and brightness. In our situation 'desaturation' along lines of constant hue may best be described as a 'veiling with the colour of the surround' instead of a 'veiling with white' [Hering, 1920/1964 *Outlines of a Theory of the Light Sense* (Cambridge, MA: Harvard University Press); English translation by L M Hurvich, D Jameson]. This indicates that, as in the case of perceptual transparency, two layers of colour are perceived.

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◆ **Colorimetry for CRT displays: almost-valid measures from invalid colour-matching functions**

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We show how stimuli from a CRT colour display can best be characterised by a user who lacks radiometric measurements, and must rely (or prefers to rely) instead on colorimetric data that are based on inaccurate colour-matching functions, in particular the (X,Y,Z) tristimulus values of the CIE 1931 standard observer. We provide transformation equations which prove able to correct the deficiencies of this observer very well. In so doing, even this somewhat discredited colorimetric standard suffices for a very accurate representation of CRT stimuli, not only relative to one another but in absolute terms, in the sense, for example, of specifying the cone contrast that CRT stimuli of different colour will form for a given class of cone. The resulting error proves to be much smaller than two other sources of error that we have also investigated and quantified: the expected variation among real observers, and the differences between competing recently proposed standard observers.

◆ **The influence of chromatic adaptation on perceived location**

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We examined the chromatic tuning characteristics of L/M and S/(L + M) opponent mechanisms by assessing the influence of chromatic adaptation upon the perceived visual location (McGraw et al, 2001 *Perception* **30** Supplement, 15). The chromaticities of the adaptation and test stimuli could be independently varied. Adaptation stimuli were restricted to the L/M and S/(L+M) cardinal axes whilst the test stimuli incorporated four additional noncardinal chromatic axes. For each combination of adaptation and test stimuli the magnitude of positional offset varied as a function of the chromatic composition of the test stimuli. For the L/M adaptation stimulus, the variation in perceived positional offset as a function of test chromaticity can be adequately described by a sinusoidal function. In contrast, S/(L+M) adaptation exhibits markedly nonlinear behaviour as a function of test chromaticity, resulting in a much narrower chromatic tuning. The effects of chromatic adaptation on this task exhibit little interocular transfer, and decay rapidly in a manner consistent with retinal afterimage formation, placing the site of generation of the effect at a point at least antecedent to the emergence of extensive binocular interaction. These human psychophysical results parallel physiological recordings in the macaque striate cortex.

◆ **Spatial features and chromatic adaptation**

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Colour constancy employs the classification and integration of edge signals over large parts of a scene. However, the properties of the actual physiological processes underlying such large field computations are little understood. In previous experiments, we found that the early time-course (0.2 s–5 s) of mid-spectral chromatic adaptation is accelerated by a cortical mechanism that responds to contrast in the adaptation pattern (Werner et al, 2000 *Vision Research* **40** 1101–1113). In our new experiments, we investigated the properties of this spatial component of chromatic adaptation. The pattern (15.4 deg × 13.2 deg) was presented on a calibrated colour monitor and consisted of horizontal stripes of different luminances. For the reference condition, it was achromatic ($u' = 0.197$, $v' = 0.468$; $L_{\text{mean}} = 19.3 \text{ cd m}^{-2}$). Chromatic adaptation was measured for the transition from D_{65} adaptation to a 5 s green adaptation light located in an equiluminous plane in colour space. The effect of chromatic adaptation was measured by a hue-cancellation technique, which involved maintaining the achromatic appearance of a central test patch (2.2 deg × 2.4 deg). Our results provide evidence for a spatial mechanism of chromatic adaptation, which responds to the spatial features of the adaptation pattern, namely its spatial frequency and orientation.

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POSTER SESSION

FACE PERCEPTION

● The influence of familiarity and distinctiveness on attractiveness

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Several studies have found that facial attractiveness is positively correlated with both rated familiarity and typicality. We proposed to manipulate familiarity to atypical faces in order to measure the effect on attractiveness. Our stimuli included 84 images of female faces, all frontal view and including hair. In our first experiment, we collected ratings for attractiveness, distinctiveness, and familiarity using three different groups of participants. Distinctiveness did not correlate with either attractiveness or familiarity. However, we found a positive correlation between attractiveness and familiarity, which is supported by evidence from cognitive-prototype theory. This result suggests that attractive faces are viewed as more prototypical or familiar than other faces. In our second experiment we tested participants' memorability for faces with high versus low degree of attractiveness. We found no difference between these faces. However, distinctiveness did accurately predict performance. Our results suggest that the distinctiveness and attractiveness of a face are unrelated, and only distinctiveness is related to memorability. This result contradicts previous findings, although, unlike those studies, our stimuli in our initial experiments included information about hairstyle. Further experiments suggested that manipulation of familiarity affects the attractiveness of that face. These results are discussed in relation to the 'mere-exposure' effect.

● The influence of familiarity on the configural face effect

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When halves of different faces are aligned, each half interferes with the identification of the other (Young et al, 1987 *Perception* **16** 747–759; Hole, 1994 *Perception* **23** 65–74). Familiarity of the component halves was manipulated to investigate how face familiarity affects this 'configural interference' effect. Six familiar and six unfamiliar male faces were used. In experiment 1, observers were presented with pairs of composite faces (aligned or non-aligned) and asked to decide whether the top halves belonged to the same or different individuals. The bottom halves were different from the top halves and from each other. Configural interference occurred regardless of familiarity with the stimuli. In experiment 2, observers were shown composite faces made of either familiar top halves with unfamiliar bottom halves or vice versa. Configural interference only occurred if the top half was unfamiliar while the bottom half was familiar. Thus, familiarity affects the configural face effect by influencing the speed with which face components are processed; ignored face halves cause configural interference only if they are processed as fast as or faster than the target half—ie when both halves are familiar, or both are unfamiliar, but not when the target half is familiar and the ignored half is unfamiliar.

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● Judgments of genetic relatedness of children

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Our object was to estimate the information about genetic relatedness visually available from facial photographs of children. The stimuli were forty-eight pairs of photographs of children. In half of the pairs, the children were siblings; in the other half, the children were not. Forty-eight observers, in a signal-detection task, judged which pairs depicted siblings. There were three occlusion conditions: sixteen observers viewed full-face photographs of the children, sixteen viewed the same photographs with the eye regions of both children masked, and sixteen viewed the photographs with the mouth regions masked. For each occlusion condition, we converted the observers' performances into estimates of Shannon information, an alternative to signal-detection measures that require distributional assumptions. The maximum possible information conveyed per pair is 1 bit. The results for each occlusion condition were: 0.36 bit (full face), 0.47 bit (eyes masked), 0.63 bit (mouth masked). We find that observers can extract considerable information about genetic relatedness from photographs of children's faces. It is remarkable that observers were able to extract more information with parts of the face occluded than they could from full faces, as if the intact face masked the facial features relevant to the task.

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● **Learning can abolish age differences in face recognition: a developmental ERP study on upright, inverted, and contrast-reversed faces**

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Expertise in face recognition increases with age and decreases with configural changes (inversion and contrast-reversal). To determine if sufficient encoding could abolish these differences in children, sixty-three 8–15-year-olds were tested in a recognition task involving inverted, contrast-reversed, and upright faces. In each trial block (six by face type), one target face was presented ten times in a learning phase, and was repeated twelve times randomly amongst 20 non-target faces of the same format in the immediately following test phase. Behaviour and ERP components indexing encoding and recognition processes were analysed in the learning and recognition phases. Effects of age were found for reaction times but not for hits, errors, and misses of targets and distractors. All children recognised upright faces better and faster than the other two face types. Age effects were found on P1, N170, and VPP components at shorter latencies and smaller amplitudes with age. Face-type effects on the N170 were found in all children. Repeated faces elicited larger amplitudes at frontal sites for all age groups and face types, suggesting a similar memory component. Thus, configural changes disrupted face encoding in all children, but, with sufficient learning, recognition performance was no longer different across age groups.

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● **Finding diagnostic features in noise**

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Improvements in signal discrimination due to perceptual learning have been described as either a reduction in internal noise or an enhancement of discriminant signal features (Doshier and Lu, 1999 *Vision Research* **39** 3197–3221; Gold et al, 1999 *Nature* **402** 176–178). Following the proposal of signal enhancement, those features enabling fine discriminations between incoming signals are diagnostic to resolve the task. We are here interested in the relationship between the diagnostic status of a feature and the perceptual learning mechanism that enables its extraction. We first derived, using the ‘bubbles’ technique of Gosselin and Schyns (2001 *Vision Research* **41** 2261–2271), the diagnostic regions used by human observers to perform a face-identity task. In a perceptual learning paradigm, using the same faces, new observers performed a 10AFC face-identity task in which we varied the information available to perform the task by applying the diagnostic mask to the face. To distinguish between the potential candidates behind improved performance we varied the contrast energy of the signal and the level of external noise added to the stimulus. Performance thresholds of the human observer were then compared with that of an ideal observer that uses all of the available information in the stimulus.

● **A comparison of the effective use of visual information in upright and inverted faces**

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While it is well known that face inversion has a large detrimental effect on recognition performance, the mechanisms underlying this effect are not yet fully understood (eg Enns and Shore, 1997 *Perception & Psychophysics* **59** 23–31). The main goal of this research was to contrast effective use of upright and upside-down information. Schyns, Bonnar, and Gosselin (in press *Psychological Science*) have recently revealed the diagnostic information for face recognition in the spatial-frequency and location dimensions, when faces are shown upright. We used the same approach for the current research: that is, we used the ‘bubbles’ technique (Gosselin and Schyns, 2001 *Vision Research* **41** 2261–2271) to directly reveal the effective use of visual information. Our stimulus set comprised 30 faces [(5 males + 5 females) × 3 expressions]. The stimuli subtended 5.72 deg × 5.72 deg of visual angle. We decomposed upright and inverted faces into 5 bands of spatial frequencies one octave apart and sampled these bands with small Gaussian windows (standard deviation = 2.15, 1.08, 0.54, 0.27, and 0.13 deg, from coarse to fine scales). We adjusted the number of Gaussian windows on-line to maintain performance at 75% correct. We ran five subjects who completed six blocks of 500 upright trials followed by 500 inverted trials. The upside-down condition required significantly more surface revealed by the windows than the upright condition. A proportion-correct-when-visible statistic was computed for each pixel (ie first-order statistics) in each condition. Special attention was given to higher-order statistics because the effect of face inversion is generally attributed to an impairment of configurational

processing (Yin, 1969 *Journal of Experimental Psychology* **81** 141–145). We found clear modulations in the effective use of information.

● **A right-hemisphere advantage for processing blurred faces**

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It is widely accepted that the right hemisphere is better than the left hemisphere at processing faces. However, evidence from normal and clinical populations and from neuroimaging studies suggests that the left hemisphere is also important in the effective processing and recognition of a face. We investigated the role of the left hemisphere in face recognition by using blurred faces. Blurring decreases the amount of featural information available from the face, but leaves configural information intact. Famous and non-famous faces were presented to the left and right visual fields. Half were blurred and half unblurred. Blurred famous faces were responded to significantly faster when presented to the left visual field (right hemisphere) than when presented to the right visual field (left hemisphere) ($t_{28} = 2.3$, $p = 0.026$). These results are consistent with an explanation in terms of hemispheric differences in preferred mode of processing. Blurred faces are more compatible with the right hemisphere's configural processing mode, than with the left hemisphere's featural/piecemeal mode.

● **Spatial-frequency band used in visual search for faces**

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The purpose of the study was to determine what spatial-frequency information is used by observers in a quick visual-search task where the observer is required to search for and identify a target face from among a set of distractor faces. Rectangular 4×4 arrays of faces were used. One of the faces was a target face and the others were distractors. A multiple-alternative forced-choice method was used to obtain the threshold search time for finding the target. Simultaneously, eye movements were recorded with a video eye tracker. Shape information was destroyed selectively by randomising the Fourier phase spectrum at a one-octave band of different centre spatial frequencies. Fourier phase randomisation at medium spatial frequencies (around 8–11 cycles per face width) increased threshold search time by more than a factor of 2, while at low (2–2.8 cycles per face width) and high (23–32 cycles per face width) spatial frequencies the effects were small. Fixation durations and the number of fixations per search also obeyed an inverted U-shaped curve so that the maximum was found at 8–11 cycles per face width. The results support previous findings according to which face perception is band-limited to mid spatial frequencies.

● **Localisation and detection of faces in naturalistic scenes**

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The localisation and detection of a face within a scene is a prerequisite of face recognition. Experiments employing visual-search tasks for faces have indicated that face detection is a serial task. These experiments, however, have typically employed grey-scale faces and jumbled faces as distractors. A series of experiments is reported in which colour-face detection was explored in more naturalistic scenes. These tasks more closely simulate the situation that face-detection systems would have been developed to handle. In experiment 1, faces do pop out of the visual arrays indicative of parallel search. This pop-out is not mediated by the colour of the faces. Indeed, the only visual transformation that was found to reduce the degree of pop-out was reversal of the luminance pattern. Consequences for computer vision and models of face processing are considered.

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● **The effect of linear perspective on face recognition**

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The use of configural information in face processing requires finding correspondence between a large number of possible patterns on a 2-D surface projected from a single 3-D face structure. Numerous studies have demonstrated the difficulty of finding such correspondence between different views of faces rotated in depth. In this study, we show that, even when a face is presented in the same view, distortions due to linear perspective can create a serious challenge for the detection of correspondent configural information. We employed face images taken by a virtual camera from the same full-face view of 3-D face models but at varying distances. Subjects were trained

on one of these image conditions. At test, the trained face was either shown in an identical image as the trained one or in one of the other images taken from different distances. A strong effect of perspective transformation on recognition performance was found. The deficit seems to show a comparable magnitude to that produced by view changes. This suggests that, although recognition of simple shapes or objects such as tiles and cubes can be effortless under perspective transformations, finding a correspondence between patterns of a complex object category, such as faces in the same situation, is not an easy feat for the visual system.

● **Vision at a glance: a high-level pop-out effect for faces**

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In the search literature, only elements that differ in basic features such as orientation or colour were thought to pop out from an array of distractors. More recent research has shown high-level concepts to pop out as well. In experiment 1, subjects were presented with line drawings of faces, cars, and houses as targets or distractors. Reaction time was independent of set size from 16 to 64 items per array when the target was a face and distractors were cars or houses, but increased with size when the target was a car or a house on a background of houses or cars, respectively. These results were obtained even when the distracting houses or cars differed in size and shape. In experiment 2, we used a variety of real-life photographs containing faces and many other objects. Search for faces still had no set-size effect, indicating that this important category is not detected by relatively slow, focused conjunction search, but by a faster system that is comparable to feature search. The results indicate the visual system may be using a fast system with spread attention to find the gist of the scene, including object categories, as suggested by the reverse hierarchy theory [Hochstein and Ahissar, 2000 *Journal of Vision* 1(3) 350a].

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● **Facial coloration, sex, and beauty**

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Cosmetics are used routinely to augment facial attractiveness. One of the more consistent uses of cosmetics is to darken the eyes and mouth relative to the surrounding skin. Two experiments were conducted to determine whether the magnitude of luminance contrast between the eyes and mouth and the surrounding skin plays a role in facial attractiveness. Black-and-white images of male and female faces were manipulated such that the eyes and mouth were darkened, lightened, or left unchanged. Subjects rated the attractiveness of all three versions of each face on a Likert scale. In the first experiment the internal features only were presented, and in the second experiment the whole head was shown. In both experiments, images of male faces were judged more attractive with lightened features than with darkened features, while images of female faces were judged more attractive with darkened features than with lightened features. Previous work with averaged faces has shown that increasing sexual dimorphisms can make a face more attractive. The present findings may be attributable to an accentuation of a dimorphism in coloration between males and females. Such a dimorphism could be related to the much higher rates of cosmetics use by women than men.

● **Perceptual salience of noses of children with cleft lip and palate**

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The noses of patients with cleft lip and palate (CLP) often show unique shapes. Bilateral asymmetry of shape and/or skewed ridge of the nose are their main characteristics. We examined what kind of unique shapes of CLP children's noses is salient. To control the features of stimulus faces, average faces of boys and girls were used. Sixteen noses of CLP children and four noses of normal children were embedded in the average faces. Two faces were simultaneously presented and twenty-one female undergraduates judged whether the two faces were the same average face or not. The judgment response times (RTs) showed that the stimulus faces embedded with CLP noses were easily distinguished from the average faces. Physical measurements of noses were carried out and the relation between the physical measurements and the RTs was examined. The bilateral asymmetry of nostrils showed a relatively high negative correlation of -0.511 between RTs. Further examinations confined to stimulus faces with CLP noses showed the relatively high negative correlation of -0.612 between the width of the nose and RTs. These results suggest

that bilateral asymmetry of noses is a salient cue for distinguishing between CLP noses and normal ones and the wider nose is perceptually more salient among CLP noses.

● **Facilitation of eye-direction judgments by incongruent directions of head and body**

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We investigated the effects of an individual's head and body directions on the judgments of that individual's eye direction. Stimuli were images of human figures in which the eyes, the head, and the body were directed either toward the viewer or to the right, and subjects judged the direction of the eyes only. There were eight types of stimuli (2 eye directions \times 2 head directions \times 2 body directions). Among these stimuli, two were completely congruent (both eyes, the head, and the body were facing in the same direction). It was expected that the response times (RTs) for the two congruent stimuli would be the shortest, because the head and body directions would facilitate eye-direction judgments for the congruent stimuli, but the head and/or the body directions would interfere with the judgments for the other stimuli. However, the actual RTs for the congruent stimuli were not the shortest among the eight stimuli. These results are inconsistent with past studies in which subjects' responses were explained on the basis of Stroop-type facilitation/interference among directional components depicted in the stimuli. The cause of the inconsistency between this study and the past studies is discussed.

● **Discrimination of familiar and unfamiliar synthetic faces by North Americans and Koreans**

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A new class of synthetic-face stimuli has been recently introduced for studying visual face processing. Synthetic faces are extracted from digital photographs of individual faces and band-pass-filtered after converting into radial frequencies for the head shape. In face-discrimination experiments Wilson et al (2002, submitted), using synthetic-face cubes, found that discrimination thresholds for highly distinctive face cubes centred on a non-mean face were 1.45 times higher than for faces centred on the mean face. These results might give us a quantitative insight into 'the other-race effect'. To investigate further this problem, we measured the face-discrimination thresholds for non-North-American faces, in this case Korean faces with Korean subjects. We found that the increment thresholds for mean face cubes for three subjects averaged 4.4% in front view and 5.6% in side view. However, the thresholds rose to 6.1% and 7.8% for non-mean front and side face cubes, respectively. In good agreement with the previous study, these results indicate that we do have finer discrimination ability for familiar faces than for unfamiliar faces. We will switch North-American and Korean faces and test each with the other group to get a quantitative measure of the 'other-race effect'.

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● **The relationship between event-related potentials and semantic distances in the recognition of facial expressions of emotion**

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Our previous studies showed that the positive components with latency of around 150–200 ms (P170) were intensified positively as the 'facedness' of stimuli increased (eg Suzuki et al, 2000 *International Journal of Psychology* **35** 333), and the amplitudes of N2 and P300 components differed among the several emotional categories of facial expressions (eg Suzuki et al, 2001 *Perception* **30** Supplement, 58–59). The present study investigated ERPs elicited in making categorical judgments of emotional facial expressions. Twelve university students participated in the experiment. They were shown three schematic faces expressing different emotions (eg happiness, anger, and neutral) repeatedly in four sessions. In each session, one face (eg a happy face) was presented 30 times and the other faces (eg angry and neutral faces) were presented 10 times in random order. Each face was displayed for 300 ms at a time. In each trial, participants were asked to make a discrimination judgment by pressing buttons. The results show that the amplitudes of P300 components differ even between two low-rate presented stimuli, the differences of which seem to correspond to the semantic distances between pairs of stimuli in the multidimensional affective space of facial expressions.

● **Forward masking of faces with three types of spatially quantised (pixelised) masks: evidence for configuration microgenesis**

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Broad-band grey-scale images of faces were forward-masked by (i) their pixelised versions, (ii) pixelised versions of different faces, (iii) pixelised noise with face-typical spectrum of spatial frequencies. Both coarseness of masker pixelation and SOA (stimulus onset asynchrony) were varied between 5 levels. Pixelised replicas of faces had virtually no masking effect at any coarseness level. The masking effect of pixelised noise increased with decrease in SOA; however, no effect of pixelation coarseness was found. The masking effect of pixelised different faces increased systematically with decrease in SOA and coarseness of pixelation. The latter result cannot be attributed to confusions of first and second stimuli because the rate of respective responses was low. At the two coarsest levels of pixelation, pixelised different faces produced no stronger masking than pixelised replicas of faces, whereas pixelised noise caused strongest masking. The results support neither the spatial-frequency model of image recognition nor the interpretation of the effects of pixelation in terms of spatial-frequency filtering. They are best explained by a coarse-to-fine, microgenetic account of processing configural information. Pixelation at a progressively more coarse level allows progressively larger distortion of configural information and both provides proto-object information for any subsequent face and facilitates spatial discrimination of mask and test images.

● **Radial-basis-function network simulation of the categorical judgments of facial expressions**

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A hypothesis can be postulated that the categorical judgments of facial expressions are based on the probability density functions of emotional categories in the multidimensional space of physical attributes. We attempted to test this by comparing a neural network simulation with data from a psychological experiment. In the neural network simulation, we created a three-layered radial-basis-function (RBF) network, with a Gaussian basis function in the hidden units. The RBF network learned the nine physical parameters of 216 schematic facial expressions of six emotions (happiness, surprise, fear, sadness, anger, disgust) drawn from Yamada (1993 *Applied Cognitive Psychology* 7 257–270). After this learning, we created another set of 180 facial expressions in a stochastically randomised way. Then we made the network classify the new set of facial expressions. In the meantime, we also conducted a psychological experiment, in which three groups of about 48 to 50 participants each (altogether 143 participants) were asked to make category judgments of different subsets (each of 60 of the 180 facial expressions). As a result, we obtained high canonical correlations between the network performance and the participants' judgments. Thus it can be concluded that the hypothesis described above is supported.

● **Do autistics perceive facial expressions in a piecemeal fashion?**

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Whilst people with autism process many types of visual information at a level commensurate with their age, studies have shown that they have difficulty interpreting facial expressions. One of the reasons could be that autistics suffer from weak central coherence, ie a failure to integrate parts of information into globally coherent wholes [Frith, 1989 *Autism: Explaining the Enigma* (Oxford: Blackwell); Frith and Happé, 1994 *Cognition* 50 115–132]. To test this hypothesis we presented autistic and (age and IQ matched) normal children with pairs of facial images. Their task was to decide whether the faces showed a similar expression, or whether either the eyes or the mouths were similar (ignoring the rest of the face). Stimuli in the latter condition were digitally manipulated, eg the eyes stemming from a happy face were composited within a face displaying sadness. Although autistics were expected to show relatively greater difficulty comparing whole facial expressions, we proposed that they should be better than normal children when judging the similarity of individual expressive features. Results are discussed in terms of the central coherence theory and current theories of visual information processing in autism.

● **Assessment of facial expression production in Parkinson's disease**

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A hybrid categorical/measurement approach is required to interpret facial displays produced by Parkinson's patients (PD) during assessment of disease progress and socio-affective impairment. Positive therapeutic intervention using facial exercises and orofacial stimulation could be assessed by an unsupervised statistical inference technique that embraces those approaches. Related patterns of expressive facial features used in non-verbal displays were identified, and eight feature primitives selected to model differences between basic emotion categories (happy, sad, disgusted, fearful, surprised, angry, neutral) conforming to received perceptual wisdom. Responding to textual or image cues, patients' expressions were filmed and scored by untrained observers using the expression model (clinical professionals, nonclinical students). Interscorer reliability exceeded 90%, underlining the ease and consistency of model usage. Analysis of PD expressions revealed superior performance due to mimicry than written instructions and the extent to which perceived flattened affect can be explained by composite displays of the upper and lower facial regions during interpersonal social engagement. Differences between voluntary and spontaneous capacities to express emotions further characterised opportunities for therapeutic support. Furnished with a simple method for quantifying impoverished facial gestures, we now propose to evaluate monitoring of facial expression exercise and commensurate physiological benefits due to positive displays.

● **Recognition of facial expressions as a time function of intensity and speed**

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How to create movies of facial expression is a critical technique for multimedia technologies. An expression intended by a creator has to be sensed by all observers. The most common idea about creating an expression is to increase the intensity of the expression linearly, but actual expressions are different from this. In this paper, the intensity of expression from a neutral face to the maximum expression is described as a time function. The experiments were performed for 36 stimuli, which were created by the combination of 4 time functions (linear, cubic root, cubic, S-shaped), 3 presentation speeds (fast, normal, slow), and 3 expressions (anger, smile, sadness). Participants described the impression of facial expression on a paper freely for the stimuli. There was an optimal combination of function and speed for which the highest intensity or veridicality for each expression was reported. The combination of a fast speed with the cubic function made the strongest impression for the anger expression. For the smile, the fast speed made a weak and low veridical impression. For sadness, there was no effect of speed but the cubic-root function made a false smile.

● **Adaptation effects in the recognition of a fearful expression**

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The ability to decode facial affect is crucial for human communication; however, controversy surrounds how facial expression recognition is processed. Aftereffects are well established as the psychologist's microelectrode to probe the workings of visual processing by desensitising the contribution of specific neural populations. Here we employed adaptation as an experimental tool to tap into the neural underpinning of the recognition of a facial expression, using linear continua of morphed faces generated between neutral expression and prototype expressions of fear, happiness, and sadness. The results have shown that prior adaptation to a prototype fearful expression as opposed to happy or sad expression biased the subsequent categorisation of fearful expressions in low strength. The results of a further experiment argue against the possibility that the observed adaptation effects could be attributed to changes in sensitivity to the configurations of fearful faces. Our current data imply that (a) there might be a distinct neural population in which fearful expressions are encoded, and (b) habituation of the emotional attributes of the fearful expression mediates the observed adaptation effects.

● **The recognition-speed advantage for happy faces. Does it originate from the stimulus or the perceiver?**

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Many reaction-time studies have shown that positive facial expressions (ie happy) are recognised faster than negative ones (eg disgust or sadness). We investigated, first, whether this effect is also evident when the physical characteristics and the difficulty in categorisation between positive and negative facial expressions is controlled. To this end, we used simple schematic drawings of facial expressions as stimuli. The results showed that the subjects still recognised emotionally positive faces significantly faster than emotionally negative ones. Second, pleasant and unpleasant odours were used to examine the effects of evaluative context on the recognition speed of facial expressions. In the pleasant odour context, positive facial expressions were recognised faster than negative ones. In the unpleasant odour context, negative facial expressions were recognised faster than positive ones. On the basis of these results, we suggest that the processing advantage of positive facial expressions is not solely explained by their visual distinctiveness. Instead, the categorisation speed of facial expressions is also affected by the perceiver's own emotions in a top-down fashion. Positive emotions are more primed than negative emotions under normal circumstances. This enhances the processing of emotionally positive signals and, thus, partly explains the observed advantage of positive facial expressions.

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● **Evaluation of a multidimensional model of facial expressions by means of figural aftereffects**

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It is a fundamental question whether facial expressions are processed categorically or continuously in multidimensional space. We investigated this issue using figural aftereffects induced by adaptation to facial expressions of emotion. We followed the method of Leopold et al (2001 *Nature Neuroscience* 4 89–94) who showed figural aftereffects for individual face identification. In this paper, subjects judged the expressions of test faces (200 ms) following 5 s viewing of adaptation faces. We measured the differences between the neutral and each of four facial expressions and created experimental stimuli with reference to the neutral face [100% (original, eg happy), 50%, 0% (neutral), –50%, –100% (opposite, eg anti-happy) (2001, Shibui et al *Perception* 30 Supplement, 53)]. Categorical conception predicts that the effects of adaptation are explained independently by each expression. On the other hand, dimensional conception predicts that the effects of adaptation are explained by the relationship in multidimensional space. The result suggests that the effects of adaptation are explained by the distances between test faces and adapting faces in the semantic dimension reported in Shibui et al (2001). This is consistent with the multidimensional continuous model of facial perception.

● **Facial expression perceived as neutral**

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Using schematic faces, we investigated what the neutral facial expression is. In experiment 1, participants were asked to deform a computer-generated schematic face until they perceived it as being emotionally neutral at first, and then continue until they perceived it as the usual baseline face after observing the schematic faces representing the six basic facial expressions of emotion (happiness, surprise, fear, sadness, anger, and disgust) obtained in Yamada (1993 *Applied Cognitive Psychology* 7 257–270). A multivariate analysis of variance indicated that the neutral facial expression is not equivalent to the usual baseline face. In experiment 2, we produced morphed schematic faces which changed gradually from neutral to each of the six basic emotions. Those schematic faces were presented in successive orders from neutral to emotional, and vice versa. Participants were asked to indicate the first image which they perceived as expressing an emotion in the former presentation condition, and as being emotionally neutral in the latter. Using these data, we identified the neutral expression area in the two-dimensional space of visual information, which consists of 'slantedness' and 'curvedness/openness' (Yamada 1993).

- **Dimensional information is primary in judgment of facial expression**

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Russell [1997 *The Psychology of Facial Expression* (Cambridge: Cambridge University Press) pp 295–320] asserted that in judging facial expression we automatically obtain dimensional information on pleasure and arousal, rather than categorical information on discrete emotions. To examine this assertion, we engaged participants in three category-discrimination tasks, in which they were asked to decide whether a target face expressed anger or fear (AF session), fear or happiness (FH session), and happiness or anger (HA session). Before target faces, visually masked prime stimuli were presented for 150 ms (conscious block) or for 17 ms (unconscious block). In each session, the prime stimuli included two faces (anger and fear in AF session, etc) and a blank (as a control). Participants were told to neglect those primes. Because anger and fear are adjacently located in a pleasure-arousal space, the priming effect should be detected only in FH and HA sessions if it was dimensional information that is processed automatically. Indeed, participants' responses were faster when target faces were preceded by congruent primes than by incongruent primes in FH and HA sessions, whereas there was no statistical difference in AF session. Our results support the view that dimensional information is primary in judgment of facial expression.

[We are grateful to Y Hashimoto and K Sakaguchi for giving us permission to use their pictures of facial expression.]

- **Critical size of visual field for the recognition of facial expression**

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Holistic information is an important factor for facial perception. However, what proportion of a face should be observed at any one time has not been studied. We therefore conducted an experiment to determine the critical size of the visual field necessary for identifying the facial expression of emotion. Six actresses displayed facial expressions of happiness, surprise, sadness, anger, disgust, and a neutral expression. The facial figures (16 cm in height) were shown on a TV screen one by one for a maximum of 5 s. The subject identified expression through one of six visual field sizes: 5 deg (12.32% of the face), 7 deg (25%), 10 deg (50%), 12 deg 10 min (75%), 13 deg 10 min (85%), and 13 deg 20 min (90%). The circular aperture was moved by the subject with a mouse. We found that (i) correct responses do not increase linearly with the size of the visual field. Good identification is achieved when the visual field is within 10 deg or 13 deg 20 min, (ii) total scanning distance traced by movement of the mouse was longer for apertures below 10 deg, (iii) the strategy to search the facial expression might change from partial feature dependence to holistic structure dependence at 50% of the face seen.

- **Influence of pupil size on the estimation of emotion from the face**

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The influence of pupil size on the estimation of emotion from faces with expression was investigated. Face images with typical expressions of happiness, anger, and fear were prepared and three variations of each face image different only in pupil size were made. Subjects were asked to rank the degree of the emotion of these three face images, with the same expression but with different pupil sizes, shown simultaneously. Subjects were also asked to rank the degree of unnaturalness of these three face images. The experimental results demonstrate that the degree of happiness and fear estimated from the faces with each expression significantly goes up with larger pupil size, whereas the degree of anger goes up with smaller pupil size. The unnaturalness of these three face images goes up with smaller pupil size, regardless of emotion. These results indicate that pupil size affects estimation of emotion from the faces, and positive influence is induced when pupil size reflects the actual pupillary response of the people in each emotion.

3-D SPACE

- **The complete rules of perspective and their instantiation in 'stereoscopic perspective'**

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It is often believed that perspective was completely understood in the early Renaissance and that artists first depicted accurate perspective and then purposefully deviated from it as they became disenchanted with its rigours. In fact, almost all artists before Degas violate one or more of the rules of linear perspective. One of the most important rules is that perspective is correct

only from a particular viewing location, but many Renaissance artists set the centre of projection at an inaccessible or awkward location. The perceptual effect of viewing perspective paintings from their veridical centre of projection is a dramatic increase in perceived depth that may be termed 'stereoscopic perspective' to emphasise its equivalence to binocular stereopsis. However, the perspective constructions of Renaissance frescos imply that, despite the widespread use of vivid perspective, artists were unaware of the stereoscopic power of perspective when viewed from the projection singularity.

- **A ground plane preference for stereoscopic slant**

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Many theories of surface perception have given preference to 'ground' planes [eg Gibson, 1950 *The Perception of the Visual World* (Boston, MA: Houghton Mifflin)]. Here we provide evidence of an asymmetry in stereoscopic slant perception, where ground planes are more veridically perceived than ceiling planes.

Observers viewed random-dot stereograms containing horizontal shear disparity. Stereograms appeared as planar surfaces slanted about a horizontal axis, framed by a frontoparallel pattern of random squares. Slant varied between $\pm 75^\circ$ and contained a proportion of uncorrelated noise (0%–60%). After viewing the stimulus, observers were presented with a probe (an adjustable line on Cartesian coordinates), which they matched to the perceived surface slant. We found that slant was generally underestimated. This underestimation was greater for ceiling planes than for ground planes. Noise reduced observers' overall perception of slant. However, this effect was also asymmetrical. For stimuli containing noise, ground planes could still be reliably perceived when opposite ceiling planes could not. We discuss the observed asymmetry from a Bayesian perspective and argue that it may constitute a prior constraint for 'ground' slanted surfaces. We further suggest that this prior has ecological validity, since it represents a common frame of reference for acting in the world.

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- **The promotion of stereo by motion**

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Models of depth-cue combination have proposed that independent depth modules may interact prior to combination to specify unknown parameters (Landy et al, 1995 *Vision Research* **35** 389–412). For example, motion parallax and binocular disparities could interact to recalibrate the viewing distance, overcoming the stereo distance scaling problem. We investigated whether, following presentation of both cues, the influence of motion on stereo-defined shape would persist when the motion was removed.

Stimuli were horizontally oriented elliptical hemicylinders, defined by stereo alone (static), or stereo plus motion about a vertical axis (moving). Stimuli were presented with various depths, and observers judged whether the depth was greater or less than the half-height. The point of subjective equality (PSE) was the depth perceived equal to the half-height. Experiment 1 consisted of three successive blocks of 280 trials: static, moving, static. The PSE in the second static block differed from the one in the first block and became more consistent with the PSE in the moving block. In experiment 2, moving and static stimuli were interleaved within a single session (672 trials). For several observers, the PSEs for static and moving conditions converged as the session progressed. We conclude that motion does influence perceived shape from stereo even after the motion is removed. This suggests the promotion of stereo by motion prior to combination of these cues.

[R A Champion is supported by an ESRC studentship.]

- **Three depths from one disparity, and slant from no disparity**

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We report two novel stereoscopic phenomena. First, we presented three equally sized rectangles separated by small vertical gaps to one eye, and a single large rectangle equal in width to the sum of the three rectangles to the other eye. The only disparity signal present was a difference in width of each eye's total image consistent with a single slanted surface. Nevertheless, three frontoparallel rectangles at three discrete depths were then seen. Second, we made the width of the large rectangle equal to the widths of the three rectangles plus gaps in the other eye. Three slanted rectangles with depth steps between them were then seen despite a complete absence of positional disparities in the stimulus. Observers set stereoscopic probes with real disparity to match perceived depth and slant. Depths and slants perceived were reliable and consistent with

geometric predictions if the large rectangle in one eye had been treated as three abutting rectangles each congruent with one of the three rectangles in the other eye. These results show that the visual system is able to arrive at a sophisticated resolution to binocular stimuli, inferring depth or appropriately graded slant, without the matching features and disparity signals considered essential for stereopsis.

● **Surface slant and surface curvature from texture**

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The contribution of texture to the perception of slant and curvature was studied in two experiments in which we collected judgments of human subjects by means of probe adjustment. For the slant-perception experiment, our stimuli consisted of flat surfaces receding away from the subject, while for the curvature experiment we used surfaces depicting half-elliptic cylinders whose major semi-axes pointed towards the subject. Both types of stimuli were generated under perspective projection with purpose written software. The surfaces were mapped with different types of textures: uniform dot lattices, polka dots, Voronoi tessellations, orthogonal sinusoidal plaid patterns, fractal or $1/f$ noise, 'coherent' noise, and a 'diffusion-based' texture (leopard-skin-like). Although we observed differences in performance for different textures, the results generally show a higher correlation between the perceived and depicted slant of a plane than between perceived and depicted curvature. These results suggest that texture may be more informative for perceiving slant than curvature. For the plaid textures, however, qualitatively similar results were obtained in both experiments. Since this is not the case for textures comparatively similar in uniformity (eg dot lattice), further spatial-frequency-based comparisons might show relevant differences for a spectrum-based shape-from-texture mechanism.

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● **The role of motion versus texture density in the kinetic-depth effect**

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Relating psychophysical data to models of the kinetic depth effect (KDE) has proven difficult owing to the presence of texture density cues in KDE displays caused by object foreshortening. Attempts have been made to eliminate this information by adding dot scintillation cues to object shape. It is assumed that at low dot densities the scintillation cue is weak, contributing marginally to the 3-D percept. We assessed the role motion, texture density, and scintillation cues play in KDE tasks by measuring rotational thresholds for (transparent) object discrimination. Three KDE conditions were tested: (i) motion + texture density, (ii) motion + scintillation, and (iii) motion alone. All thresholds were measured as a function of dot density. Results indicate that element motion alone supports object recognition, and that there is no effect of texture density cues at any dot density. In contrast, performance is significantly enhanced by scintillation, at all dot densities. This finding calls into question the practice of adding a non-ecological scintillation cue to KDE stimuli on the grounds that it will produce spuriously low thresholds. We conclude that there is a purely motion-based object recognition process, and that the role of texture density in the KDE depends critically on the nature of the stimuli and task used.

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● **Detection of illumination direction from texture**

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Texture is often due to the illumination of surface irregularities. The luminance pattern presented to the eye is due to small-scale cast shadows, shading variations, and interreflections (multiple scattering). These optical phenomena depend upon the nature of the material (eg whether the surface is diffuse or specular at a microscale), the shape of the surface at the scale of 'textons', the nature of the source (eg sunlight or overcast sky), and the illumination geometry (effective light direction, viewing direction, direction of nominal surface normal). The 'texture' for a single material indeed depends critically upon illumination and viewing parameters (which is why 'shape-from-texture' does not work very well in many realistic settings). Can the human observer infer the illumination direction from the texture? In order to find out, we used samples from the curet-database (available at <http://www.cs.columbia.edu/CAVE/curet/>). Only frontal views

were selected, and each sample was presented under a variety of directions of illumination. Observers indicated perceived direction of illumination. We obtained data for dozens of illumination directions, dozens of materials, and five observers, permitting a fairly detailed statistical analysis. Data were correlated with statistical descriptions of the image structure. In a final analysis we relate performance to material structure.

● **A model for the appearance of the Mach book based on parallelism and perpendicularity of lines in space**

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The Mach book is an example of a figure which appears in depth, although it does not contain any classical depth cues. A simple model for the appearance of such figures was based on two assumptions: first, all lines which have the same orientation in 3-D facilitate each other, and second, lines which meet at a vertex have a mutual inhibition which is least when they are perpendicular. The model was tested on a restricted set of line drawings, consisting of those which are made up of lines in any of three orientations: vertical and $\pm 60^\circ$ to the vertical. The model predicted the 3-D appearance of figures such as the Mach book and also variants such as Attneave's triangles and Mackworth's figure. The model involves only simple contextual facilitation of parallel and perpendicular lines in space, which could easily be performed as early in the visual pathway as V1. The facilitation of parallel lines in space might form part of a broader computational strategy of identifying parallel lines which are invariants of the stereoscopic and motion parallax transformations.

● **Neural correlates of shape from shading**

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The perception of shape from shading is ambiguous because the position of the light source is frequently unclear. In previous studies, we showed that human observers solve the shape-from-shading problem by assuming that light is coming from above-left, rather than straight above (Mamassian and Goutcher, 2001 *Cognition* **81** B1–B9). In the present study we have investigated the neural bases for this intriguing light-position bias. We have recorded event-related potentials (ERPs) from 32 electrodes placed on the scalp of ten healthy participants while they looked at ambiguous shaded stimuli. Depending on the assumed light-source position, the stimuli were interpreted as frontoparallel surfaces with either wide or narrow strips protruding out in relief. We presented the stimuli at different orientations and asked observers which strips appeared in relief (narrow or wide). The light-source position most consistent with the participants' perceived shape averaged 14 deg left of the vertical when the stimuli were presented foveally. We found a strong correlation between individual light-position biases and ERPs at temporal electrodes for the P1 time window. These results suggest that shape from shading is disambiguated in the first 100 ms after stimulus onset. We discuss these results in light of a bottom-up mechanism for shape from shading.

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● **Discrimination of surface reflectance of 3-D shape**

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The luminance of light scattered from a surface is a composite function of the reflectance, the illumination, and the viewing direction with respect to the surface normal. Veridical perception of reflectance thus requires separate representations of the components corresponding to different physical causes. We examined how observers interpreted reflectance differences of faces of regular polyhedra. Stimuli were simulations of two rotating dodecahedra presented on the two halves of a CRT screen. Three levels of diffuse reflectance (0.2, 0.5, and 0.8) and three different lighting modes (collimated, hemispherical diffuse, and ambient) were used to render the faces of the two polyhedra. On each trial, the reflectances of six faces of one of the two polyhedra were randomly perturbed. Observers had to choose which polyhedron was perturbed. Thresholds for discriminating nonuniform from uniform polyhedra were highest in the collimated lighting mode followed by the hemispherical diffuse lighting mode, and finally the ambient lighting mode. The level of diffuse reflectance was not of any influence on the discrimination thresholds. The ability to discriminate surface reflectance is better for hemispherical diffuse lighting than for collimated lighting. In the ambient lighting case, there is no impression of 3-D shape; there the task becomes contrast detection.

- **Illusory depth motion of objects and background surface induced by dynamic cast shadow**
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When an object's cast shadow moves on a background surface, shadow motion can be the result of the displacement of either the light source, the object, the background, or one's viewpoint. Yet, object motion in depth is usually the dominant percept (eg Mamassian et al, 1998 *Trends in Cognitive Sciences* 2 288–295). We test here whether cast-shadow motion can also induce motion in depth of the background surface. We simulated a 3-D scene of spheres (objects) in front of a frontoparallel checkerboard surface (background) and moved the light source so as to induce cast-shadow motion. Across trials, we manipulated the number of objects (2–20), whether the objects stayed stationary or moved horizontally, and whether the background stayed stationary or slid diagonally. Participants judged if the objects or the background appeared to move in depth. We found that the perception of object motion in depth increased when the number of objects decreased and when these objects moved. In contrast, the perception of background motion in depth increased when the number of stationary objects increased and when the background slid. These results suggest that the visual system interprets cast-shadow motion as background motion in depth when image motions are accidental for object motion and generic for background motion.

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- **Comparison of pictorial reliefs for identical two-dimensional images in different orientations**
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For shape perception in pictures, depth cues such as shading play a crucial role. Shading depends upon the light-source direction and the orientation of the objects. In this study, the influence of image orientation is investigated. We used six different photographs of a torso. In these pictures the pose of the torso was varied, but the rest of the scene was kept constant. The grey-scale pictures were shown on a flat frontoparallel computer screen centred in the straight-ahead direction. Each of the six photographs was viewed in four different orientations with orientation differences of 90°, presented in random order. We measured the pictorial reliefs by the method of adjusting an elliptical gauge figure superimposed (in red outline) on the torso at different locations. Only one probe was seen at a time, presented in random order. The pictorial reliefs reveal significant differences that can be described well by overall shears, accompanied by part-wise differentiations related to clearly defined regions on the surface of the torso. We have encountered the same kind of transformations previously. They can be interpreted as 'mental eye movements'. Here these are apparently induced through the unfamiliar orientations.

- **Functional isovists as descriptors of spatial perception**
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Gibson's theory of ecological perception has received considerable empirical and theoretical attention within psychology. Over the past 35 years, however, architects and space analysts have developed a quantitative theory of space representation which is similar to Gibson's notions of perception. Specifically, it is argued that first-person representations of visual space and the use of transitions between vistas can accurately portray some aspects of the way humans think about space. With this in mind, two experiments were carried out. Participants were primed with a brief view of a partially occluded scene. They were then presented with a 300 ms view of several objects, the spatial locations of which they were asked to reproduce. Perceptions of object location were significantly more accurate in cases when the second scene was viewed from a position within the field-of-view of the priming scene, compared to control scenes from different points-of-view. In a second experiment, participants were asked to generate distinct views of a novel space that would maximise the amount of spatial information conveyed. Consistently, views which featured many transitions were favoured above views which led to a depiction of the greatest total volume. The utility of this method for representing space is discussed.

● **Judging the direction of 'above' in a tilted room**

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In the absence of information about the origin of illumination, people interpret surface structure by assuming that the direction of illumination is from above. Here we investigate the influence of the frames of reference defined by head and body orientation, gravity or visual cues on judgments of 'above'. Sets of four grey, shaded discs were used that differed in the polarity of their shading. Observers indicated with a four-button response pad which of the four discs appeared most convex and thus indicated the direction of their perceived 'above'. Sets of discs were shown in a cross formation on a grey laptop screen arranged with the keyboard in the normal configuration relative to the body. Observers were positioned lying on their side in either an upright room or in a specially constructed room tilted by 90°.

The pattern of responses indicates that the perceived direction of 'above' is influenced by both the direction of gravity and the visual frame (defined by both the laptop and the surrounding room). When the room was tilted, the visual cue pulled the perceived direction of 'above' away from the direction defined by gravity.

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● **The influence of individual roll-tilted lines and their combinations on perceived vertical: experiments and theory**

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We describe three experiments that employ roll-tilted lines of different orientations and lengths, and pairwise combinations of these lines that generate influences on perceived vertical (VPV) as large as those produced by the classical square frame. In experiment 1, length of the one-line inducer was varied from 3 deg to 64 deg at each of 7 roll tilts between -13.2° and $+13.2^\circ$. The slope of the VPV-versus-roll-tilt function increased from 0.14 to 0.50 with line length. Experiments 2 and 3 each consisted of 49 conditions in which the orientation of each of two bilaterally symmetrically located equal-length lines was independently varied; the two were simultaneously presented; inducer line length was 12 deg and 64 deg, respectively. The influence of the two-line stimulus in each case was a linear combination of the influences of the two individual lines, although complete summation was approximated for the short line and averaging for the long line. Similar results were previously obtained with the same lines on another dimension of ego-centric space perception, the elevation perceived as eye level (VPEL), although there bilaterally symmetrically located lines of the same orientation yield equal and opposite influences, whereas for VPV these lines yield identical influences. Recently we described a three-stage neural model (Matin and Li, 2001 *Vision Research* **41** 2845–2872) that accounts quantitatively for VPEL data with inducing lines of different orientations, lengths, and different numbers of lines. A similar model accounts for the VPV results.

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● **The tradeoff between the two basic aspects of perceived space**

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Perception of space is affected by various stimulus parameters, eg length intervals in the fronto-parallel plane are typically perceived as longer than physically equivalent in-depth intervals. We hypothesise that orientation as well as other stimulus parameters determine the perception of two basic aspects of space in common: length together with direction. In the outdoor experiment, the subjects observed two white sticks positioned on a sandy ground. The distance between the sticks was held constant (1 m). Their orientation varied from the possible values of 0°, 30°, 60°, or 90° with respect to an observer's sight. Their distance from the observer was 2, 5, or 10 m. The task was to place the third stick so that it perceptually matched the distance and the direction of the interval defined by two original sticks. We focused primarily on the variance of judgments. As the stimulus orientation got farther from the line of sight, the variance of adjusted lengths gradually decreased and at the same time the variance of adjusted directions gradually increased. The results indicate an inherent relationship between both descriptors and it is therefore reasonable to consider the perceived space to be essentially two-dimensional.

● **The perception of apparent depth: from cue combination to cue competition**

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Stimulus cues such as contrast, interposition, or partial occlusion critically influence the perception of apparent depth in pictorial (2-D) displays. We (Dresch, Durand, and Grossberg *Spatial Vision* in press) have shown recently that contrast cues may either cooperate or compete, depending on the spatial configuration, with other depth cues such as interposition or partial occlusion. The stimuli we used were briefly presented pairs of achromatic line drawings. Subjects had to decide which figure of a given pair seemed 'nearer' to them. Here, we present data from new experiments using the same experimental procedure. The stimuli were achromatic and coloured line drawings. The results show that, in the same way as achromatic contrast, colour either cooperates or competes, depending on the spatial configuration, with interposition cues and cues of partial occlusion. Colour, however, is found to be the stronger depth cue than an achromatic contrast cue of the same luminance. How the relative weight of a given depth cue may produce cooperation or competition with other cues is discussed in the light of cortical mechanisms of visual grouping.

● **The zooming diamond illusion and the projective schemes appropriate to modelling biological vision**

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In the 'zooming-diamond' effect, a diamond-shaped lamina appears to approach and recede when it is rocking and rotating on a fixed pivot, so that it passes through a frontoparallel orientation, then through one where the long axis is aligned with the line of sight, then back to frontoparallel (Cowie, 1997 *Perception* 26 Supplement, 49). The percept is incompatible with the display according to familiar models of projection, but it is consistent with 'weak perspective' (ie shape and orientation information are handled as if projection were parallel, distance and size as if it were polar). The effect is strongest with simulated objects, but it persists when real objects are observed in reduced viewing conditions. Further experiments with simulations show that observers do describe shape as if projection were parallel, and identify a function that might control apparent depth. The theory of weak perspective implies that ambiguities involving distance and orientation should affect laminae, but not 3-D objects. Tests confirm that 'zooming' disappears as the diamonds become thicker. The effect can also be cancelled by simulating approach and recession in counterphase. The effect offers a visually compelling reminder that it is an empirical question which projective schemes apply to biological vision.

EVOKED POTENTIALS

● **Assessment of stereopsis in early stages of Alzheimer's disease using visual evoked potentials**

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Alzheimer's disease (AD) is a progressive neurodegenerative disorder that is associated with visuospatial deficits. According to some psychophysical studies, it could also affect stereopsis (Cronin-Golomb, 1995 *Gerontologist* 35 370–376). The aim of our study was to test this possibility electrophysiologically, by recording visual evoked potentials (VEPs) to checkerboard stimuli perceived as moving in depth (stereo condition) or laterally (motion control condition) for 2 s. We tested probable AD patients, age-matched healthy controls, and young healthy participants. There were significant differences between young and elderly participants, such as higher early and decreased later activation in elderly. However, similar differences between stereo and motion conditions were found in both control groups: the latency of stereo VEP peaks was longer than the latency of motion VEP peaks. Differences in stereo and motion specific activation were also reflected in VEP subtraction waveforms. A further analysis revealed that the amplitude and latency of stereo VEP peaks in AD patients were within ± 2 SD of the control group's average stereo VEP. These findings show that there were no significant differences in stereo-evoked brain electrical activity between our probable AD patients and the healthy age-matched controls. The implications of these results are discussed.

[We thank our participants for their help and patience, J E W Mayhew and Hector-Gabriel Acosta-Mesa for valuable discussions.]

- **Event-related brain potentials reveal three loci of repetition priming for written names**
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We assessed immediate repetition priming effects for famous names on reaction times (RTs) and event-related brain potentials (ERPs). Participants performed speeded familiarity judgments for famous and unfamiliar names. In experiment 1, famous target names could be preceded either by the same name or by the same name in a different font, or by a different famous name (unprimed). In three different time ranges after target name onset, we observed three topographically different ERP modulations of priming. Between 180 ms and 220 ms, a posterior N200 modulation was seen only for font-specific name repetitions. Between 220 ms and 300 ms, a left temporal negativity (N250r) was seen both for same-font and for different-font repetitions. Between 300 ms and 400 ms, a reduced central-parietal negativity (N400) was seen for primed names. In experiment 2, famous target names were preceded by either the corresponding famous face (cross-domain priming), or by the face of a different celebrity. Whereas the N400 priming effect was preserved, no N200 or N250r effects were seen. This suggests that the present N200, N250r, and N400 effects reflect facilitation at the levels of font-specific encoding, lexical entries for names, and semantic integration, respectively. These results demonstrate that ERPs are an efficient means to isolate separable processes involved in repetition priming.

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- **Are different cortical generators involved in the processing of first-order and second-order patterns?**

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Information about visual objects may be coded by (first-order) modulations of luminance and (second-order) of carrier contrast and these two types of spatial information may be processed by distinct mechanisms. The aim of this study was to explore the properties of visual evoked responses to first-order and second-order noise patterns. We recorded VEPs to suprathreshold first-order and second-order patterns of $0.5 \text{ cycle deg}^{-1}$ and $4 \text{ cycles deg}^{-1}$, in the presence of either static or dynamic noise. The Laplacian responses, which reflect mainly striate activity, were computed. We found the Laplacian response for $0.5 \text{ cycle deg}^{-1}$ gratings was positive with a latency of around 120 ms, while gratings of $4 \text{ cycles deg}^{-1}$ elicited negative Laplacian responses with a latency of around 90 ms. The waveforms in response to first-order stimuli in the presence of noise were similar to those in the absence of noise. However, second-order stimuli of both $0.5 \text{ cycle deg}^{-1}$ and $4 \text{ cycles deg}^{-1}$ evoked a negative component of around 130 ms for static noise, and 200 ms for dynamic noise. As second-order stimuli evoked a response of opposite polarity to first-order stimuli, for $0.5 \text{ cycle deg}^{-1}$, one might suggest that first-order and second-order vision may have different cortical generators. Further, the longer processing time required for second-order stimuli indicates that these pathways might have different temporal characteristics.

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- **Using Wiener kernels to model visually evoked potentials**

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Using electrodes attached to the scalp, we recorded visually evoked potentials (VEPs) in response to a checkerboard stimulus that was reversing. VEPs were recorded under different viewing conditions: monocular right, monocular left, and binocular. We wanted to compare the monocular with the binocular viewing conditions while considering the questions: (i) How does neural activity elicited by monocular viewing differ from the activity elicited by binocular viewing of the stimulus? (ii) Is the response greater or smaller in the binocular condition than in the monocular condition? and (iii) Would one expect suppression, or a reduced response, in the binocular condition, because of binocular rivalry.

VEPs were recorded from fourteen normal subjects, and transformed into first-order and second-order Wiener kernels, producing a model of the response, which is a multiple-regression model. The order of the kernel describes how many response values are simultaneously multiplied, weighted, and summed into the total response. Multiple-regression analysis was used to calculate the additivity of the two eyes and to establish the relationships between the viewing conditions and stimuli. We found that there is binocular rivalry and that the response for any single eye is greater than the response in the binocular condition. There is an effect of sparseness which is greater in the monocular than in the binocular condition, and which appears to be smaller in the superior visual fields. Responses are greatest to the very sparse stimuli. We conclude that VEPs could be used for diagnosis of multiple sclerosis and glaucoma. Since we have

eight different kernels, increased peak latencies in any of the visual regions will spot small plaques, which would be otherwise hard to detect with simpler stimuli. Higher-order kernels show reduced peak amplitudes in glaucoma patients.

● **The manipulation of orientation and spatial-frequency components of noise gives rise to opposing effects on the visual evoked response**

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Visual white noise is rich in orientation and spatial-frequency information, which activates large populations of neurons in the striate cortex. The early component of the visual evoked potential (VEP) mainly reflects activity of striate neurons. We wondered how different orientation and spatial-frequency components of visual noise might affect the electrical responses of the striate cortex. Onset VEPs were recorded from Oz, O3, and O4 in normal adults to: a 5.6 cycles deg⁻¹ grating; white binary noise samples; noise samples filtered with centre frequency of 5.6 cycles deg⁻¹ into one-, two-, and three-octave bands; noise samples filtered into one-octave bands and transmission within 45°, 90°, and 135°. All stimuli had root-mean-square contrast of 8%. Three-point Laplacian analysis was performed on the averaged VEPs to extract the early striate response whose latency was around 110 ms. The amplitude and energy (summed squared amplitude) of the Laplacian responses increased significantly with increasing orientation range and decreased significantly as the range of spatial frequencies increased. The results indicate summation of the activity of neurons sensitive to different orientations and suppression between spatial-frequency channels. This latter effect may be due to inhibition between these channels and to reduced sensitivity at lower and higher spatial frequencies.

● **Wiener kernels for the early detection of multiple sclerosis**

R Ruseckaite, T Maddess, A C James (Centre for Visual Sciences, RSBS, Australian National University, Canberra, ACT 2601, Australia; e-mail: Rasa.Ruseckaite@anu.edu.au)

Visual evoked potentials (VEPs) are being used for the prediction of early glaucoma and multiple sclerosis (MS). We investigated whether VEPs, presented as Wiener kernels, are a useful tool to diagnose MS as well. Study group contained fifty MS subjects (with optical neuritis) and twenty normal subjects. VEPs were recorded in a dichoptic viewing condition, for four sparsenesses (binary, intermediate, sparse, and pattern pulse). VEPs were transformed as Wiener kernels and processed by means of multivariate regression analysis and singular values decomposition method. The linear and quadratic discriminant analysis was also applied. We found that VEP voltages were significantly smaller for the MS study group. They were also more 'delayed' (approximately by 40 ms) than the data from normals, and comprised different waveforms. This can be explained by optical neuritis. Optical nerves can be damaged in different places, thus evoking different waveforms in the potentials. We have also found that the cortical singular-values-decomposition component appeared faster than the retinal one. Results show that the Wiener kernel method can be applied to process VEPs and to extract specific MS features. The features mentioned above could be used in a discriminant data analysis which assists to classify normals and MS subjects and to diagnose MS at an early stage.

● **Comparison and clinical application of objective indices of chromatic VEP selectivity**

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To objectively assess the purity of chromatic VEPs in subjects who may be unable to specify equiluminance subjectively we compared the two new indices of chromatic VEP selectivity by retrospectively analysing published VEP waveforms recorded from adults, infants, and animals. The same indices were then used to analyse the purity of chromatic VEPs evoked from children and amblyopic adults. The degree of chromatic VEP response selectivity was expressed as one of two indices: onset negativity/(onset negativity + onset positivity) or onset negativity/(onset negativity + offset positivity).

In adults, chromatic VEPs elicited at equiluminance are characterised by a predominant negative wave, offset VEPs by a positive component. Small departures from stimulus equiluminance result in VEPs with an additional early positive component and larger offset components which resemble contrast reversal and achromatic VEPs and which lower both indices of selectivity. At equiluminance, the indices approach unity. At extreme departures from equiluminance, the early positivity and offset components dominate the waveform and the ratio approaches zero.

Onset negativity/(onset negativity + onset positivity) most faithfully reflects departures from equiluminance. The criteria facilitate rapid assessment of response selectivity without the need for recording time-consuming additional controls, and prove useful clinically in cases where subject cooperation is limited or visual function impaired.

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● **Evidence that chromatic-specific VEPs reveal an additional mechanism contributing to red/green processing**

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Our aim was to investigate the temporal properties of mechanisms responding to isoluminant S-cone-specific (tritan) and red–green (R–G) gratings. We used coarse, equiluminant tritan and R–G gratings to elicit onset VEPs, verified for chromatic selectivity by comparison with chromatic-reversal or achromatic-onset VEPs. VEPs were characterised in terms of waveform and temporal-tuning characteristics. In addition, tritan and R–G VEP integration times were determined. Simulations were performed to examine possible interactions between onset and offset components for different stimulus durations. Tritan onset VEPs were found to be negative (monophasic); R–G VEPs had an additional early negative component. Tritan and R–G reversal VEPs showed low-pass and bandpass temporal tuning respectively. Tritan onset VEPs were of maximum amplitude when gratings were presented for 160–200 ms. Onset VEPs to R–G stimulation were of maximum amplitude when onset durations were 60–100 ms with a secondary maximum for onset durations of 160–200 ms. The simulations suggested this did not reflect electrical interaction between onset and offset components. We conclude that the temporal properties of VEPs to equiluminant tritan and R–G gratings differ and suggest that an additional mechanism contributes to R–G responses.

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● **EEG correlates of unitary and mixed perceptual periods in multistable visual perception**

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Presentation of an ambiguous figure as well as of two different images shown simultaneously to the two eyes results in multistable perception which is characterised by alternating periods. Between the two consistent interpretations seen in the unitary periods, patchwork-like images combining features of both are seen in the mixed ones. Here we examined whether unitary and mixed periods have different electrophysiological correlates. For the rivalry task, two different photographs of faces were presented to the two eyes, while the classic ‘husband/father-in-law’ picture was used as the ambiguous figure. The perceptive state of fifteen subjects was continuously recorded as well as EEG from ten active leads. EEG power and coherence were analysed separately for the two types of perceptual periods. Results show that, in both conditions, EEG gamma coherence (22 Hz–48 Hz), but not power, differentiated the periods. In the binocular rivalry condition, a widespread synchronisation process accompanied the periods of unitary, and a local posterior effect the periods of mixed perception. In contrast, for the ambiguous figure, a reverse tendency in the form of widespread synchronisation in the mixed periods was notably reduced during the unitary ones. The results suggest that under conditions of ambiguity the perceptual disambiguation requires coherent activation of a wide network.

LOCAL MOTION

● **Retinal ganglion-cell signals with moving targets: accurate at any speed**

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Vernier performance with moving targets is accurate independent of velocity. Is this inherent in ganglion-cell responses or must central mechanisms integrate activity to achieve this invariance? Precision of responses to bars and gratings was assessed by neurometric analysis. For magnocellular (MC) cells, spatial precision with bar stimuli was independent of movement speed; this was not so for parvocellular cells. For gratings, precision was maximal for MC cells at low temporal frequencies and increased above ~6 Hz. With slow stimuli, rates are low but the many impulses give precise spatial information. With rapid movement, peak rates are high but the few impulses give noisy signals. MC-cell spatial precision resembled human performance, so these

features are utilised psychophysically. This constrains central motion mechanisms. The neurometric result required analysis over several hundred milliseconds. However, near-optimal performance is achieved with brief presentations (<100 ms). This is resolved if central spatiotemporal filters extract a motion signal by combining/comparing activity of a small sub-mosaic of cells. Secondly, in the motion tasks, human performance correlated with cell signal-to-noise ratio. In other tasks such as flicker detection, human performance correlated with peak cell rates. This difference may arise from multiple detectors, or a single more sophisticated central comparator or detector.

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- **Reverse correlation in macaque area MT**

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We measured the temporal dynamics of direction/speed tuning and receptive field structure in motion-sensitive neurons of macaque area MT using a new reverse-correlation technique. For direction/speed tuning we presented a large random-pixel array covering the classical receptive field with motion impulses (8–13 ms) in eight different pseudo-random directions, at different speeds. For mapping the receptive-field structure, smaller patches were presented simultaneously at different locations with motion impulses either to the preferred or the anti-preferred direction. Spike trains of the neurons were recorded and reverse-correlated to the stimulus sequence. Although for some cells temporal tuning varied with direction, for most cells temporal characteristics were similar at different directions. The temporal response profiles were biphasic with an excitatory phase (40–70 ms) and a delayed inhibitory phase (80–100 ms). This biphasic characteristic was speed-dependent showing stronger biphasic profiles at higher stimulus speeds (30–40 deg s^{-1}). The receptive-field-mapping measurements showed that the inhibitory surround is not evenly distributed, and that the response to the inhibitory surround is delayed to that of the centre (5–20 ms). The delayed response in the receptive-field surround suggests an extra processing stage for inhibitory input to the MT surround.

- **Spatio-temporal tuning of motion coherence detection in cats and humans**

M J M Lankheet (Department of Functional Neurobiology, Utrecht University, Padualaan 8, NL 3584 CH Utrecht, The Netherlands; e-mail: m.j.m.lankheet@bio.uu.nl)

Step size and delay tuning for direction discrimination of moving random-pixel arrays (RPAs) were measured in cats and humans. Performance was measured with a signal-to-noise threshold in a Quest staircase. The noise consisted of an incoherent RPA transparently added to the moving RPA. Cats were trained to indicate the perceived direction of motion with their paws. First, a single-step-pattern lifetime (SSPLT) stimulus was used, in which patterns on alternate frames make a coherent step and are being refreshed. Since there is no correlation over multiple steps, motion detection is necessarily based on the specific combination of step size and delay. Results show a limited range of step sizes and delays supporting direction discrimination. Second, thresholds were measured for motion seen through a bar pattern orthogonal to the direction of motion. In this case, one expects maximal interference if the width of the bars equals the preferred step size. Results, indeed, show minimal sensitivity at intermediate bar widths, corresponding to the preferred step size for SSPLT stimuli. If differences in spatial resolution and velocity tuning are properly compensated for, data for cats and humans are in good correspondence with each other, and with bilocal motion detection.

- **Tuning characteristics of luminance-defined and contrast-defined motion in depth**

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A variant of the Pulfrich illusion was used to investigate first-order and second-order motion in depth. Independent control over temporal and spatial frequency revealed different spatiotemporal tuning for the two stimulus types. Stimuli were presented to the left and right eye on a calibrated CRT display with a refresh rate of 120 Hz in a split-screen Wheatstone configuration. Stimuli were luminance-modulated or contrast-modulated sine-wave gratings behind a Gaussian envelope. On each trial subjects verged on a fixation cross flanked by nonius lines as the gratings oscillated sinusoidally for 2 s. After each presentation subjects had to indicate whether direction of motion in depth was clockwise or counterclockwise when viewed from above. Interocular phase difference between left and right gratings ($-\pi/4$ to $+\pi/4$) was randomised over trials to determine a discrimination threshold. Spatial frequency (1 to 3 cycles deg^{-1}) and temporal frequency (0.5 Hz to 3 Hz) were systematically combined in different sessions. Phase thresholds for the discrimination of luminance-defined motion in depth showed bandpass temporal-frequency tuning whereas thresholds for contrast-defined motion in depth were elevated and showed broad-band tuning.

These characteristics suggest that second-order motion in depth is due to pooling of residual first-order activation.

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● **Does position determine 2nd-order displacement thresholds?**

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It is well known that motion can be perceived through direct detection of velocity or through tracking the change in position of an object over time. A recent study (Seiffert and Cavanagh 1998 *Vision Research* **38** 3569–3582), with separate 1st-order and 2nd-order stimuli, has shown that 2nd-order motion is more readily detected with a position-based mechanism. In the present study we used a stimulus configuration and paradigm that allowed a direct comparison to be made between position and displacement thresholds for 1st-order and 2nd-order motion. Displacement thresholds were measured with Gabor patches, each comprising a stationary 1st-order carrier whose contrast was windowed by an oscillating 2nd-order envelope. The minimum spatial offset detectable was measured as a function of carrier spatial frequency, and thresholds were compared to bisection acuity thresholds measured with identical stationary Gabor stimuli. Our results show that bisection acuity thresholds remain relatively unaffected by carrier spatial frequency. At high carrier frequencies (12 cycles deg^{-1}), displacement thresholds were similar to bisection thresholds, suggesting that displacement detection is mediated by analysis of position. However, unlike bisection thresholds, displacement thresholds improved linearly as carrier frequency was reduced, indicating the importance of 1st-order spatial structure in determining thresholds for envelope displacement.

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● **A novel slant to second-order motion**

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It is widely believed that second-order motion is perceived through the operation of a nonlinear channel. In this channel, standard motion analysis is preceded by some nonlinearity, which transforms the input, essentially making second-order motion readily accessible to standard motion-computation algorithms. The strongest reason for proposing the existence of a pre-processing nonlinearity is the belief that second-order motion cannot adequately be detected by 'linear' mechanisms (ie standard motion computation without a pre-processing nonlinearity). Here a recent and novel approach to the processing of second-order motion and motion in general is described. A local gradient-based analysis is applied to second-order motion sequences. The technique allows one to assess local stimulus velocities that may be accessed by a standard-motion-computation algorithm. It is demonstrated that second-order velocity information is directly present in many second-order motion sequences such that the motion can be directly extracted by a linear mechanism. No pre-processing nonlinearity is required. It is argued that psychophysical studies of second-order motion implicitly assume that a single mechanism for first-order and second-order motion must detect the two as if they were the same. The pattern of results described in this study implies that this is not necessarily the case.

● **Tuning for step size delay in directionally selective complex cells in cat area 18**

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To study tuning for step size and delay of a moving random-pixel array (RPA) in area 18 special complex cells, we measured their directional selectivity using a single-step pixel lifetime (SSPL) motion stimulus. SSPL motion contains motion information at a single combination of spatial displacement and temporal delay, thereby allowing us to characterise the cell's preferred motion parameters. Single units were recorded with receptive fields within 10 deg of the fovea. RPAs consisted of 50% dark and 50% light square pixels. First, the preferred direction of the cell was determined for several different pixel sizes. For the preferred direction at the optimal pixel size, we determined the preferred velocity for several pixel sizes. The preferred velocity did not differ substantially for different pixel sizes (0.12–0.48 deg). Next, an SSPL stimulus was presented, which moved in the preferred direction and non-preferred direction. Stimuli moved at the preferred velocity, which was constructed by using different combinations of step and delay. Cells were bandpass tuned to a specific combination of step size and delay, rather than to velocity, for a pixel size of 0.24 deg.

● **The spatial properties of opponent-motion normalisation: lateral vs superposition masking**

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The Adelson–Bergen model (1985 *Journal of the Optical Society of America A* **2** 284–299) computes motion as the difference between directionally opposite energies E_L and E_R . However, Georgeson and Scott-Samuel (1999 *Vision Research* **39** 4393–4402) found that direction discrimination is better described by motion contrast (C_m)—a metric that divides opponent energy ($E_L - E_R$) by flicker energy ($E_L + E_R$). Previously, using lateral masking, we showed that opponent-motion normalisation is localised in orientation, scale, and space. In this study we revisited the issue using superposition masking. Observers reported the drift direction of 1.9 cycles deg⁻¹ vertical sinusoids superimposed on counterphasing sinusoids. We measured C_m thresholds whilst varying the orientation or spatial frequency of the counterphasing sinusoid. We found that C_m , but not opponent or flicker energy alone, uniquely determined performance. C_m thresholds improved as the difference in orientation or spatial-frequency between drifting and flickering gratings increased. Thresholds from superposition masking were higher and marginally less selective for flicker orientation and spatial frequency. We conclude that the spatial properties of opponent-motion normalisation in lateral and superposition masking are similar. The selectivity of normalisation for orientation, scale, and space disagrees with models (eg Heeger, 1992 *Visual Neuroscience* **9** 181–197) in which excitatory inputs are suppressed by a non-selective pool of inhibitory inputs. [SR and WM supported by US Public Health Service grants EY-4885 EY-1319.]

● **Apparent-movement detection with chromo-luminance modulated concentric stimuli**

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The interaction between chromatic-contrast and luminance-contrast components and their contribution to detection of patterns and direction of apparent movement was studied. Human psychophysical responses were obtained for an apparently moving modified Bessel stimulus of 10 deg with varying amount of chromatic and achromatic contrast. The moving stimuli consisted of four frames with a phase shift of 90° between successive frames, contracting or expanding. The stimuli were modulated in a bipolar fashion along R/G and B/Y cardinal axes. Directions of apparent-movement thresholds were set for two spatial frequencies (0.5 and 2 cycles deg⁻¹) and three temporal frequencies (2.5 Hz, 5 Hz, and 12.5 Hz). In general, the loci of thresholds are arranged according to a power summation equation: $C^n = C_{\text{chromatic}}^n + C_{\text{luminance}}^n$. In most conditions, chromatic and luminance modulations are consistent with independent (probabilistic) contribution ($n = 4$), like that previously reported for gratings, pattern detection, and stereopsis. However, summation of chromatic-contrast and luminance-contrast signals with independent noise in each channel ($n = 2$) is evident in some conditions of moderate movement. Thus, apparent-movement detection mostly relies on independent chromatic and luminance inputs, and summation seems to occur for slow to moderate movement.

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● **Evidence for object representation in the ‘where’ stream of visual pathway: mismatch-negativity study**

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Visual processing is divided into two systems: the ‘what’ stream dealing with objects and the ‘where’ stream processing spatiotemporal information. By the use of mismatch-negativity paradigm, it was demonstrated that there is a non-attentional processing of sensory information in the ‘where’ stream (Kremláček et al, 2001 *Perception* **30** Supplement, 62). The study has shown that a difference in probability of motion direction can be discriminated in the occipito-parietal area without signs of motion adaptation. To reveal if the non-attentional processing in the ‘where’ stream is capable to detect more complex stimulus properties, we used a direction sequence as the discrimination information between standard and deviant stimulus (one sequence = two-step motion). A *t*-test on the weights of the first principal component in the recorded motion-onset

VEPs showed significant differences between standard and deviant conditions (in the signal from occipito-parietal leads). This result suggests that besides basic characteristics—like motion direction—there is also a virtual representation of simple objects—like sequence of events—in the ‘where’ stream.

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● **Reaction times to changes in the velocity vector of visual motion**

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A random-dot pattern moved vertically (V_1) within an invisible aperture. The motion abruptly changed both in speed and direction (V_2). In experiment 1, simple reaction times (SRTs) to the changes in the velocity vector were measured. Angles of change of 20°, 60°, and 120°, speeds V_1 of 4 and 8 deg s⁻¹ were used; speed V_2 varied from 0 deg s⁻¹ (motion offset) to 1.5 V_1 . In experiment 2 choice reaction times (CRTs) were measured: the subjects pushed a left button to indicate a direction change to the left and a right button to indicate a change to the right. Angles of 20° and 80°; speeds V_1 of 0, 4, and 8 deg s⁻¹; and speeds V_2 between 2 and 12 deg s⁻¹ were used. It was found that the SRT for all speeds and angles can be described by a common decreasing function of a single parameter $|a(V_1 - V_{2v}) + bV_{2h}|$, $a + b = 1$, $a < b$; V_{2v} and V_{2h} being the vertical and horizontal components of V_2 . The CRTs for all speeds and angles can be described by a common function that solely depends on V_{2h} ; unlike the SRT, the CRT was independent of the initial speed V_1 . Aspects of motion information that determine the processes of simple and choice reactions are discussed.

● **Non-motor contributions to motion deficits in schizophrenia**

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We investigated fine speed and fine direction sensitivity in schizophrenia after eliminating the influence of eye movements. Nineteen patients with schizophrenia and nineteen controls participated in the study. A trial consisted of two random-dot cinematograms (RDCs), each presented for a duration (200 ms) too brief for reliable eye movements. The two RDCs on each trial differed from each other in both the speed and direction of motion. The task was randomly varied, requiring each subject to make either speed judgments or direction judgments, while the stimulus conditions were held constant across these two tasks.

ANOVAs indicated that controls outperformed patients on both speed discrimination ($F_{1,36} = 12.11$, $p = 0.0078$) and direction discrimination ($F_{1,36} = 11.7$, $p = 0.0096$). By contrast, a control experiment revealed that time-discrimination thresholds were statistically indistinguishable for patients and control subjects ($F_{1,36} = 2.924$, ns). This suggests that the patients' deficit on the speed task was not based upon time cues that were available in the stimulus. The patients' deficit was not entirely motion-specific, however, as controls significantly outperformed patients on a battery of brightness-discrimination tests. The findings suggest that eye-movement deficits in patients with schizophrenia are not entirely motor in origin.

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● **Onsets and transits of visual motion**

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Response times (RTs) to onsets and transits of visual motion were compared within the same thirty-two subjects. Following an acoustic warning, a luminous dot (diameter 9 min of arc, grey background) was exposed 6 deg left of fixation with variable delay (500 ms–800 ms). The target moved rightward at 2 deg s⁻¹ for 1 s (onset condition) or 3 s (transit) and then disappeared. The task was to press a key as soon as the target started to move (onset RT) or as it crossed a static reference 2 deg from fixation (transit RT); there were 60 measurements in each condition. There was no correlation between onset and transit RTs. Mean onset RT was 258 ms, while the mean transit RT (2002 ms) was almost identical with the actual time of stimulus transit (2000 ms), indicating a compensation of response latencies. Both RT distributions were positively skewed and best fitted by a Weibull function; however, the distribution of transit RTs was less skewed and much broader than that of onset RTs. The observed high variability of transit RTs may result from a competitive interplay between bottom–up mechanisms with top–down modulation (anticipative–attentive control).

● **Experimental study on speed perception**

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The discrimination of speed at suprathreshold level was analysed by using a group of three dots moving coherently on a background of dynamic visual noise. The orientation and direction of movement of the target group varied as follows: (i) horizontal movement on the fixation point, and above and below it, with a right–left direction, and vice versa; (ii) the same thing for a vertical movement passing over the fixation point and outside it, in a downwards direction, and vice versa; (iii) a random movement embracing the whole frame. The speed of the target varied between 90 and 30 frames s^{-1} . The 20 functions obtained presented variable exponents between 0.55 and 1.2. For the same speed estimation, the situations that required greater speed for detection were those that passed through the centre of fixation, particularly downwards. With a larger number of distractors these situations could not be recognised. The situations requiring lower speed were those that presented horizontal movement from right to left situated below the fixation point, and also the one that presented random movement. The situations that had not been recognised at first, could be recognised with the addition of colour both to the target and the background.

[Supported by CONICET]

AWARENESS

● **Individual differences in alphanumeric-colour synaesthesia**

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For alphanumeric-colour synaesthetes, viewing a black letter or digit elicits a conscious experience of a highly specific colour (ie a photism). Synaesthetes' descriptions of the photisms elicited by letters and digits suggest that not all synaesthetes experience their photisms in a similar fashion. For 'projector' synaesthetes, the colours appear 'on the page' overlaying the letter or digit and adhering to the shape of the grapheme. In contrast, for 'associator' synaesthetes, the colours are not projected; rather they are experienced 'in the mind's eye'. Projector synaesthetes can be distinguished from associator synaesthetes in two different ways: (a) by the patterns of Stroop-type interference that occur when either the video colours of coloured digits are named or the photisms elicited by coloured digits are named, and (b) by the differences in performance found on a perceptual-grouping task where grouping stimuli on the basis of synaesthetic colours enhances performance. The findings indicate that there are at least two types of alphanumeric-colour synaesthetes, and it is suggested that unless projector and associator synaesthetes are considered separately, erroneous conclusions may be drawn from investigations of alphanumeric-colour synaesthesia.

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● **Attention modulates the binding of information across the 2-D visual array**

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We examined the modulating role that attention exerts on the integration of information in space and time to produce the common perceptual experience of a line and a square. The design comprised a 2-D search space, made of four distinct spatial locations (one per element of a line in experiment 1 or per corner of a square in experiment 2) by eight temporal lags (linear increments of 26.6 ms with an eighth lag of 400 ms). In each trial (lasting 667 ms), a fixation cross appeared first for 1 s followed by a line constructed from three synchronous and one asynchronous element whose position and temporal asynchrony were randomly sampled from the 2-D space. We manipulated attention with a non-predictive cue, presented for 67 ms above one element position (the left and right elements of the line in experiment 1; one of the four corners in experiment 2), but only 150 ms prior to asynchrony onset, to rule out eye movements. In a 2AFC task, observers responded whether the stimulus was continuous or discontinuous. We found that the perceptions of the continuous line and square were warped in space–time around the foci of attention.

● **Spatial localisation, discrimination, and awareness of visual events in cortical blindness**

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Patients with visual field defects after lesions of occipital cortex are phenomenologically blind. Remarkably, if forced to respond, some of the patients show residual visual capacities such as detection of the presence or absence of targets, wavelength discrimination, orientation discrimination, and saccadic and manual spatial localisation. Residual capacities in the absence of any acknowledged awareness is termed (type 1) blindsight. In some instances the residual visual capacities may accompany a very limited awareness of the events (type 2 blindsight). The patients, however, maintain that they had no direct experience of the relevant target attribute (such as its position). We have investigated the ability of four cortically blind patients to manually localise the position of sine-wave gratings, or to detect their presence/absence in a two-alternative forced-choice paradigm for a range of stimulus parameters. Remarkably, dissociations between the different capacities are easily obtained, but they appear to depend on type 1 and type 2 performance categories. The results are discussed in terms of dissociable streams of visual processes and their independent, parallel relations with conscious visual awareness of events.

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● **Speed dependence of motion-induced spatial misalignment**

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We investigated a motion-induced spatial-mislocalisation phenomenon (Whitney and Cavanagh, 2000 *Nature Neuroscience* 3 954–959) as function of the speed of the motion. A rotating (40 rev min⁻¹) black bar (2.4 deg) on a white background was flanked by two smaller horizontal bars (10.8 min of arc) that were flashed briefly. We measured the apparent vertical misalignment of the flashed bars as function of angular position of the rotating bar relative to the position of the flashes using a binary-choice psychophysical procedure. The greatest spatial shift occurred when the flashes appeared before the bar reached the horizontal. Typically, at lower speeds more advanced positions of the bar produced the greatest effect. It would appear that the perceived spatial position of the flash is being updated by the motion information over this crucial period of time (approx 100 ms).

● **Motion updates perceived spatial position**

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The introduction of real or illusory motion to texture within a stationary object can produce marked changes in the position of the object as a whole. These findings suggest that recurrent input from motion-sensitive area V5 may dynamically update positional representation in lower cortical areas (V1/V2). We tested this idea directly by disrupting area V5 following motion adaptation, and examining its effect on the perceived position of subsequently presented objects. Prior to the test phase, subjects adapted to two Gabor stimuli in which the carrier gratings drifted in opposite directions. The test stimulus consisted of Gabor patches presented in a 2-blob vernier alignment configuration. Adapting and test stimuli were spatially coincident. Following carrier-motion adaptation, all four observers showed a substantial misalignment of the elements of the test stimulus in the direction of the illusory motion (8.41 ± 0.90 min of arc). Transcranial magnetic stimulation (rTMS) of V1, delivered immediately after adaptation, had little effect on the magnitude of the shift (8.39 ± 0.91 min of arc). In contrast, rTMS of V5, regardless of hemisphere, resulted in significantly reduced positional offsets (right V5: 4.72 ± 1.06 min of arc; left V5 4.46 ± 1.42 min of arc). These results support the notion that neurons involved in the analysis of motion continuously update the positional representation of objects.

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● **Misperception of moving stimuli depends on task**

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Most popular explanations of the flash-lag or Fröhlich effect (eg differential latency or extrapolation) assume that the relationship between psychometrically estimated qualities (simultaneity or perceived spatial phase) conforms to the structure of physical variables. We show that the estimated time and space of a dynamic event do not necessarily form a physically congruent structure. Observers judged either initial position or onset time of a moving bar with regard to

an appearing stationary bar. The test bar moved to the left or right with a constant velocity (4.2, 8.2, 16.3, or 32.7 deg s⁻¹). From the estimated spatial phase between the moving and stationary object it was impossible to predict the temporal asynchrony that was needed to make the stimuli apparently simultaneous and vice versa. Independently of velocity, the perceived onset position almost coincided with the actual position of the bar, but the perceived onset moment was delayed increasingly less as the velocity increased. We conclude that (i) for the movement onset, the temporal and spatial properties are disassociated; (ii) unlike physical variables, the perceived distance is not directly convertible into perceived time under reasonable assumptions about velocity; (iii) the (mis)perception of moving stimuli cannot be understood without an explicit psychophysical model of how perceived attributes are internally represented.

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● **The flash-lag effect does depend on events before the flash**

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The flash-lag effect occurs when an object is flashed adjacent to the path of a smoothly moving object, and abreast of the moving object. The flashed object appears to spatially lag the moving object in the direction of motion. A number of theories of this effect incorporate the assumption that only events happening after the flash contribute to the processing which results in the flash-lag effect (Eagleman and Sejnowski, 2000 *Science* **287** 2036–2038; Krekelberg and Lappe, 2000 *Science* **289** 1107), although Eagleman and Sejnowski later conceded that the extent to which this is true may be a matter of degree, depending on the ‘saliency’ of the flash. We used a flash-initiated paradigm, where the moving object only started moving when the flash appeared, and varied how long the moving object was stationary before the flash appeared, from 0 ms to 750 ms. The moving object moved at 12 deg s⁻¹, and was approximately 4.5 deg from fixation when the flash occurred. Stimuli were white on a black background, and the flash was extremely salient. Contrary to these theories, we found, with four participants, that as the length of time the moving object was stationary was varied from 0 ms to 50 ms, the magnitude of the flash-lag effect was significantly reduced.

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● **The Fröhlich effect and the onset repulsion effect**

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Memory for the initial location of a moving target was examined. It has been reported previously that memory for initial location may be displaced (a) forward in the direction of motion—the Fröhlich effect (Kirschfeld and Kammer, 1999 *Vision Research* **39** 3702–3709; Müsseler and Aschersleben, 1998 *Perception & Psychophysics* **60** 683–695); or (b) backward in the direction opposite to motion—the onset repulsion effect (Hubbard and Motes, 2002 *Cognition* **B89**–B99; Thornton, 2002 *Spatial Vision* **15** 219–243). Targets were presented within a large enclosing window, and the initial location was either adjacent to or a small distance from one side of the window. Targets moved across the window and vanished when either adjacent to or a small distance from the opposite side of the window. When initial location was adjacent to one side of the window, memory exhibited a Fröhlich effect, whereas when initial location was a small distance from one side of the window, memory exhibited an onset repulsion effect. Displacement patterns were consistent with the hypothesis that the proximity of the initial location of a moving target to the edge of a larger enclosing context may influence whether memory for the initial position exhibits a Fröhlich effect or an onset repulsion effect.

● **Motion blindness explained by frontal gating**

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Transient deficits in visual motion perception can be obtained in normal observers by means of rapid serial visual presentation (RSVP). In previous studies we have shown that irrelevant distractor motion preceding a target motion serves as a precondition for ‘motion blindness’. Here, we examined the gradual changes in motion processing brought about by increasing numbers of distractors. Event-related brain potentials (ERPs) were recorded for the experimental condition in which a central colour cue indicated the onset of global target motion and two control conditions in which motion stimuli had to be continuously treated either as relevant or irrelevant by subjects ($n = 15$). Sensory posterior processing (as reflected by N200 amplitude) was found to be attenuated with increasing numbers of motion stimuli, independent of condition.

Specifically related to motion blindness in the experimental condition was the gradual build-up of a frontal negativity (225 ms to 275 ms), which we propose to be the electrophysiological correlate of a post-perceptual frontal gating mechanism. Motion distractors at late positions evoked significantly attenuated amplitudes of a centro-parietal positivity (P3) compared to motion at earlier positions. Visual events that have passed sensory processing possibly fail to reach conscious representation whenever the reported frontal generator has been activated.

● **On the novelty of 'motion-induced blindness'**

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Bonneh et al (2001 *Nature* **411** 798–801) demonstrated 'motion-induced blindness' (MIB), in which prolonged viewing caused blindness for target dots in a moving background. They argued that such a phenomenon did not result from retinal adaptation or sensory suppression, and that the moving background was critical for MIB to occur. In this study, we examined their two arguments for MIB's novelty: (i) the fading duration increased (but did not decrease) with contrast; and (ii) there existed a 'protection zone' surrounding the target that did not disappear with the target. Two background patterns—50% black–50% white random dots and 1% blue random dots in a black field—were used, and these dots were either static, in random motion, or in coherent motion. A target dot with different contrast was superimposed on the centre of a solid square and presented at various eccentricities. Results showed that even static backgrounds induced blindness for the target dot and the square, and the functions of fading duration \times contrast were similar for all background patterns. Only at near eccentricity was the protection zone observed. Therefore motion was not critical for MIB, and its mechanism may not differ substantially from perceptual filling-in.

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● **Patterns of eye movements during motion-induced blindness**

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Bonneh et al (2001 *Nature* **411** 798–801) reported a phenomenon of 'visual disappearance'. When a global moving pattern is superimposed on high contrast stationary stimuli, the latter disappear and reappear alternately. They termed the phenomenon 'motion-induced blindness' (MIB). MIB results showed that it is unlikely to reflect retinal suppression or sensory masking, but rather is a result of a conflict generated between cortical representations of dissociated stimuli which shifts the system dynamics into a winner-takes-all mode. Other interpretations refer to attentional mechanisms, which cannot be allocated or divided between dissociated elements at the same spatial location, and at the same time. The purpose of this study was to investigate the attentional mechanisms underlying the MIB phenomenon as reflected by patterns of eye movement. Using an eye-tracking system, we have detected relations between eye-movement patterns and gaze directions, with subjects' reports of display component 'disappearance' during an MIB situation. Study results have revealed effects of time schedule/eye-movement dependence on target appearance and disappearance (eg target reappearance preceded by a specific eye-movement feature). We have also revealed depth-perception effects, which might be reflected by specific dynamic patterns of binocular convergence. Results support the view that attentional mechanisms underlie the MIB phenomenon.

● **Orientation-selective adaptation in motion-induced blindness**

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When a global moving pattern is superimposed on a stationary object, the latter disappears and reappears alternately for periods of several seconds. This phenomenon is called 'motion-induced blindness' (MIB; Bonneh et al, 2001 *Nature* **411** 798–801). We used an adaptation paradigm to determine whether orientation-selective adaptation exists in the MIB condition. In the first experiment, we found the optimal contrast in which a robust adaptation was achieved for the Gabor patches. In the second experiment, we obtained the minimum delay between the adaptation and test periods by which the effect of adaptation disappeared. In the third experiment, the adaptation to a Gabor patch was measured during blindness period if it was within the optimal delay time. The results showed that orientation-selective adaptation was preserved even when the Gabor patch perceptually disappeared to the subjects. Difference between same-adapt target and different-adapt target was significant for the blind stimulus ($p < 0.0001$) and was not significant for the control condition in which the adaptation stimulus was not presented during

the blindness period. Since orientation information is processed in low-level visual areas like V1, we could conclude that MIB may be originating in an area higher than V1. These data also support the idea that neural activity in V1 is not a 'neural correlate of consciousness'.

● **Distance-dependent compulsory averaging of crowded signals**

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In the spatial-crowding effect, subjects are unable to report the orientation of the crowded target; however, they can estimate the average orientation by compulsory averaging of local orientation signals (Parkes et al, 2001 *Nature Neuroscience* **4** 739–744). Distance dependence of this averaging was studied by two experiments. In the first experiment, subjects reported the orientation of a Gabor patch in the crowding condition in which distractors were arranged in a crossed array. Distractors whose orientation was similar to the target were presented near to or far from the target stimulus. In the second experiment, the eccentricity effect of similar distractors with the target was considered by locating the distractors in a radial array. The results showed that near similar distractors improve the performance more than far similar distractors ($p < 0.0001$). The best performance was obtained with distractors all similar to the target, which confirmed the averaging process for crowded signals. The results of the crowding experiment with the radial array demonstrated the pure effect of distance and significant interaction of eccentricity with distance ($p < 0.01$); however, there was no significant effect of eccentricity ($p = 0.83$). We conclude that improvement in performance through similarity between target and distractors is dependent on distance. So near similar distractors give more weight for the averaging process.

[With thanks to Reza Rajimehr and Farshad Moradi for their useful comments.]

● **A critical duration effect in suprathreshold pattern discrimination**

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The existence of critical duration effects in the integration of stimulus energy at threshold has been known since 1885 following Bloch's observations. Evidence is presented that a critical duration effect also occurs in a suprathreshold-pattern-discrimination task. Twelve observers performed a speeded, successive, 480 trial, same/different discrimination task. One of six randomly selected patterns was shown on a monitor screen for 500 ms and after a blank interval of 1200 ms was followed by a second pattern, either randomly the same or different, which was displayed for a variable duration between 20 and 1000 ms. Decision times showed a significant effect of exposure duration ($F_{7,77} = 2.65$, $p = 0.02$), with minima occurring at 80 ms and 120 ms. Error rates were low (5%) and did not show an effect of pattern duration. In a second experiment, simple RTs to the same set of patterns at the same exposure durations were examined and a small but non-significant rise over the exposure durations from 20 ms to 120 ms was found ($F_{7,77} = 1.74$, $p = 0.11$). It is concluded that decision times for successive same/different discriminations are fastest with exposure durations in the region of 80–120 ms.

● **Distributions of the perceptual switches associated with viewing ambiguous stimuli**

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The ambiguous Necker cube stimulus appears to switch between two alternative perspectives, 'cube-up' and 'cube-down', such that the inter-switch interval gives percept duration. Percept frequency, plotted as a function of duration, is modelled by a gamma distribution, and the model fit is improved by discarding arbitrarily durations greater than three standard deviations above the mean (Borsellino et al, 1972 *Kybernetik* **10** 139–144). Alternatively, good fits can be achieved by discarding the 'dead period' at the beginning of the distribution that represents the observer's decision time between a switch and the subsequent response with a key press that signals the switch (Martin, 1967 *Papers in Psychology* **1** 2).

Twenty-nine naïve observers recorded switches between cube-up and cube-down percepts. During a total observation period of 10 min, observers recorded up to 300 switches. We found that the best fits were generated with the gamma distribution when the 'dead period' was discarded. Arbitrary trimming of the tail, three standard deviations above the mean, had little impact on goodness-of-fit. This suggests that (i) the perceptual changes can be adequately modelled as a simple stochastic process, and (ii) the modelling is improved by accounting for the decision time between switch and response.

● **Generating ogives to (i) analyse perceptual changes associated with ambiguous figures, and (ii) reaction times in an inhibition-of-return (IOR) task**

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The perceptual changes (PCs) associated with viewing an ambiguous figure like the Necker cube (NC) can be considered as a series of independent events in time. The time between successive PCs is then percept duration, and the frequency distribution of percepts plotted against duration is adequately modelled by a gamma distribution (Borsellino et al, 1972 *Kybernetik* **10** 139–144). A logarithmic transformation on the duration scale enabled us to model the subsequent distribution with a Gaussian. The cumulative Gaussian fitted to the normalised ogive allowed simple comparison of observer performance in different conditions. We found no differences between ogives generated for the standard 'cube-up' and 'cube-down' 3-D perceptual alternatives. When observers recorded 2-D perceptual alternatives, the ogives were shallower and shifted to the right. This suggests that the neural mechanisms governing PCs between 3-D and 2-D perceptual alternatives differ from those that govern the PCs between the opposing 3-D perceptual alternatives of 'cube-up' and 'cube-down'. Further, we show that the same analysis can be applied to reaction times generated in an inhibition-of-return (IOR) task. We argue that this form of analysis is superior to other more commonly reported methods for both attentional and PC data.

● **Binocular rivalry between faces**

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Our aim was to characterise binocular rivalry (BR) between faces. Dichoptically viewed 'face' and 'anti-face' stimuli elicited BR. In experiment 1, consisting of over 90 trials, subjects pressed one key when the left face dominated entirely, and the other when the right face dominated entirely. A BR coherence index, based on the proportion of complete rivalry dominance, was calculated. In experiment 2, subjects detected brief (100 ms) contrast increments in one face while it was entirely dominant, and in separate blocks, while it was entirely suppressed. Thresholds for dominance relative to suppression measured suppression depth. Although stimuli of this size (6 deg × 6 deg) usually engage in piecemeal rivalry, this was rarely observed: rivalrous alternations between upright faces tended strongly to be coherent. Scrambling the spatial phase of one face reduced BR coherence for the other, intact face. Pairs of inverted faces rivalled less coherently than upright pairs, but still much more than upright/inverted pairs, which overwhelmingly exhibited local, piecemeal rivalry. Suppression depth was greatest for upright pairs, and was reduced by phase scrambling one of the faces. The data are consistent with the notion that rivalry can occur at several cortical levels, with higher-level rivalry producing greater perceptual coherence and greater depth of suppression.

● **Variability and adaptability in the visual system**

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The visual system is highly tuned to adapt to the changing visual environment. Setting priorities right and generating appropriate explicit representations of visual features in real time is not a trivial task. This is particularly true in cases of multistable perception, such as ambiguous figures and binocular rivalry. A number of studies (eg Logothetis et al, 1996 *Nature* **380** 621–624; Kovacs et al, 1996 *Proceedings of the National Academy of Sciences of the USA* **93** 15508–15511; Taya and Mogi, 1999 *Perception* **28** Supplement, 135) have presented evidence that higher features and salience crucially affect the ocular dominance pattern in binocular rivalry. Here, we present a model of binocular rivalry. Recurrent connections between the early visual area (V1) and form and motion area (IT and MT, respectively) are assumed to play an essential role. Simulation results suggest that the ability of the visual system to adapt dynamically to visual features and salience is contingent on a certain level of variability of neural firings within the visual system even in the absence of dynamic visual features. This result leads to a novel functional interpretation of the universal existence of firing variability observed in the central nervous system, and puts visual perception within the broader framework of fluctuation-related biological phenomena such as stochastic resonance (eg Marino et al, 2002 *Physical Review Letters* **88** 40601–40604).

● **Face-selective regions of the fusiform gyrus, but not the superior temporal sulcus, predict awareness when viewing ambiguous face stimuli**

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Physiological studies using ambiguous figures have provided important clues into the relationship between neural activity in the brain and visual awareness. This is because the physical nature of the retinal stimulation does not change, and therefore any shifts in perception will be mirrored only by brain areas directly involved in awareness. Here, we used Mooney images to discern how one aspect of vision, awareness of faces, is represented in visual cortex. Using functional magnetic resonance imaging, we localised face-selective activity in the fusiform gyrus (FG) and the superior temporal sulcus (STS) when human subjects viewed grey-scale photos of faces and an assortment of common objects. We then monitored these regions while subjects viewed Mooney images. Using an event-related design, we compared activity during periods when a face was perceived with activity from intervals when a face was not perceived. The perception of a face was accompanied by a relative increase in activity within the FG, but not in the STS. We conclude that face-selective areas in the FG are specialised for the global awareness of the face, whereas areas in the STS may be more concerned with details of facial structure that are important in other aspects of cognition.

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● **Posterior parietal multimodal dichotomous feedback control of internal and external environment**

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Posterior parietal function may be divided into two categories: that related to internal and that related to external environment. An attempt is made to form an outlook allowing continuity of these domains. Posterior parietal multimodal integration of sensory inputs is taken as the basis of construing body scheme, body-in-space, whole body awareness, and extrapersonal space; this is modulated by top-down attention processes. Examination of parietal lesion cases has led to postulating parietal feedback control with salience to maintenance of homeostasis. This is fed by bottom-up inputs of internal-environment autonomic processes. When one examines health driven by a 'feeling of wellbeing' one finds in lesion cases a remarkable loss of such feeling. Microelectrode recording in awake monkey, trained on reaching to visual targets in context of operant behaviour in extrapersonal space, revealed special characteristics in IPL neurons: of coding events, of monkey's or trainer's hand location, and movements inwards or outwards of monkey's extrapersonal space, and of multiple-duty neurons uniquely 'learning' to respond to stimuli in the course of behavioural experience. Dynamic aspects were revealed. Tactile cells of PF region of IPL show touch response at learnt targets, but not at 'no target', ie extrapersonal space loci are behaviourally highlighted.

CONTRAST AND CONTOUR

● **Masking by fast gratings**

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Perception of an oriented pattern is impaired in the presence of a superimposed orthogonal mask. This masking effect most likely arises in visual cortex, where neuronal responses are suppressed by masks having a broad range of orientations. Response suppression is commonly ascribed to lateral inhibition between cortical neurons. Recent physiological results, however, have cast doubt on this view: powerful suppression has been observed with masks drifting too rapidly to elicit much of a response in the cortex. We show here that the same is true for perceptual masking. From contrast discrimination thresholds we estimated the cortical response to drifting patterns of various frequencies, and found it greatly reduced above 15–20 Hz. In the same subjects we measured the strength of masking by the same patterns and found it equally strong for masks drifting slowly (2.7 Hz) as for masks drifting rapidly (27–38 Hz). Fast gratings thus cause strong masking while eliciting weak cortical responses. Our results can be explained by lateral inhibition if one invokes cortical neurons that respond to unusually high drift rates and yet do not make their signals available for perceptual judgments. A more parsimonious explanation is that masking is mediated by feedforward signals from the thalamus.

● **Contrast detection thresholds in the presence of flanking bars**

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Lateral masking experiments showed that detection of a small Gabor patch surrounded by Gabor stimuli was impaired at small separations (1–2 periods of the test grating). For larger separations facilitation was found (Polat and Sagi, 1993 *Vision Research* **33** 993–999). To extend this study to another type of stimulus, we measured contrast detection thresholds for thin vertical lines (1, 2, or 3 min of arc width, 1 deg length). The test line was flanked on both sides by high-contrast vertical lines having the same width and length. A temporal 2AFC method incorporated a staircase procedure. The observer's task was to report the interval in which the test central bar was presented. The separations between the test and the flanks varied from 1 to 30 min of arc. Regardless of the widths of the test and flanking bars, contrast detection thresholds increased within the area of 6–8 min of arc between the flanking lines. The thresholds decreased with increasing separations and then reached a plateau. Our results can be explained by changes in sensitivity of particular filters due to the presence of surrounding patterns (Morgan and Drespi, 1995 *Vision Research* **35** 1019–1024; Yu and Levi, 1997 *Vision Research* **37** 3117–3128), rather than by lateral interactions between spatial-frequency filters.

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● **Second-order mechanisms for orientation and contrast interact when they act as cues for segmentation**

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Strong contrast modulation (CM) of a noise carrier produces a segmented appearance of adjacent strips of weak and strong noise. Orientation modulation (OM) of an anisotropic carrier produces an undulating appearance when the orientation of the modulation is perpendicular to the baseline orientation and a segmented appearance when the two are parallel. Since the output of a single oriented channel (preferring the baseline orientation) could be modulated similarly in response to changes in orientation (output falls as orientation varies from baseline) and contrast (output falls with falling contrast), it is possible that OM and CM are detected in one mechanism. Using a 2IFC 'dipper' paradigm we presented target CM stimuli against OM backgrounds of varying strength. We varied absolute phase within each interval to remove positional cues. When the OM background had a segmented appearance and contrast troughs aligned with the baseline orientation, we found perithreshold facilitation and suprathreshold masking. When contrast peaks aligned with the baseline orientation we found weak evidence of early inhibition. This phase-dependent 'dipper' was not found when the OM background produced an undulating appearance. These results suggest that mechanisms for OM and CM have a weak interaction when segmentation occurs but are independent otherwise.

● **Ability to use phase information in discrimination of second-order patterns**

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Human performance in discrimination of luminance patterns is significantly improved when advance phase information is available as compared to that in the absence of phase information. We tested whether humans could use phase information contained in second-order patterns. Observers were presented with a pedestal or a pedestal plus a signal with a fixed phase shift relative to the pedestal (signal/pedestal amplitude ratio of 7:9). The second-order pattern consisted of 2 cycles deg^{-1} contrast modulations of a 10 cycles deg^{-1} grating. We measured the detectability d' for the discrimination of the signal at relative phase angles of 0° , 112.5° , and 180° . Cross-correlator performance would be independent of the phase angle. Phase-insensitive performance is based on the difference in energy between the two alternatives and would have zero d' at 112.5° . We found that the observers' performance in the signal-known-exactly task differed significantly from the phase-insensitive predictions, suggesting imperfect phase-sensitive discrimination. Similar results were obtained for first-order luminance gratings. In addition, we measured d' in the presence of external Gaussian noise. Using the equivalent-noise approach, we found that the internal noise in discrimination of second-order patterns was significantly higher as compared to that in discrimination of first-order patterns. This finding might reflect the presence of an additional demodulating stage in the second-order mechanism which adds extra noise.

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● **Within-texture alignment improves human texture segmentation**

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Spatial arrangement has been shown to be a critical factor both in detection facilitation of a threshold target by collinear flankers and in detection of smooth chains within random arrays of suprathreshold elements. Here, we investigate the effect of alignment between texture elements on human texture perception. Texture displays, consisting of arrays of lines, were presented to observers for 100 ms. In the discrimination task, one stimulus presentation was made and observers reported the orientation of a central block, which differed from the surround by the orientation of its elements. The detection task also used a 2AFC procedure. The degree of alignment within stimuli was varied either by increasing orthogonal offset between line elements or by decreasing the length of chains of aligned elements. Both alterations result in an overall reduction of collinearity within the display. A close-spaced and a far-spaced condition were tested, with an end-to-end distance between elements of 0.7 and 1.5 element lengths respectively. Global element density was kept constant. For most conditions, alignment was found to improve thresholds. Our results suggest that collinearity between elements results in both short-range and long-range interactions, which contribute to the formation of a texture-defined surface.

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● **Influence of spatial-frequency selectivity and spatial extent on the contrast-sensitivity function**

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Contrast-sensitivity function (CSF) is usually assessed by using stimuli derived from sinusoidal gratings the characteristic of which is a constant spatial extent whatever the spatial-frequency content. Nonetheless, contrast coding in the retina is based on circular ganglion cells of various width and related spatial-frequency tuning. Comparison of CSF determined with vertical sinusoidal gratings in a constant Gaussian blur function (high and constant spatial-frequency tuning, large and constant spatial extent) and with two-dimensional difference-of-Gaussian profiles (DOGs, one octave spatial-frequency tuning, spatial extent fitted to the spatial-frequency content) allows us to analyse the influence of spatial-frequency selectivity and spatial extent on CSF. In each category, six stimuli were used ($0.4 - 12.8$ cycles deg^{-1}). In any case, thresholds were low with low-spatial-frequency stimuli and increased as higher spatial frequencies were considered. The main difference appears for high spatial frequencies, higher contrast being required to detect DOG functions than gratings. This is consistent with a larger number of receptive fields involved in grating detection for the high-spatial-frequency stimuli. Moreover, variations in contrast threshold with DOG stimuli characterised by a constant relative spatial extent do not question the dependence on CS on spatial-frequency content.

● **Effects of grating spatial frequency on the response speed**

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The effects of grating spatial frequency (SF) on the response speed are here shown to depend on factors such as stimulus presentation and observers' task. Reaction times (RTs) and visually evoked potentials (VEPs) to sinusoidal gratings of 1 and 12 cycles deg^{-1} were compared under three conditions: (i) grating SF was constant within a group of trials, observers responded to a stimulus appearance; (ii) the two SFs randomly varied from trial to trial, subjects responded to stimuli of both SFs; (iii) the two SFs randomly varied, subjects responded only to gratings of a given SF. RTs increased at higher SF in conditions (i) and (ii). However, no significant effect of SF on RT was recorded in condition (iii). The latencies of averaged VEPs were delayed at higher SF only in the case of constant SF [condition (i)]. When SF varied [conditions (ii) and (iii)], the early VEP waves registered at 1 and 12 cycles deg^{-1} converged on a single latency. The amplitude variations of the waves depended on the observers' task and not on the grating SF. Single VEP data analyses were performed in an attempt to explain the present results in terms of a SF-uncertainty mechanism.

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● **The perceived contrast of a border is determined by the lowest spatial-frequency channel**

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Evidence from masking and filtering studies suggests that objects such as letters and quantised images are encoded by a single spatial-frequency channel (Solomon and Pelli, 1994 *Nature* **369** 395–397; Pelli, 1999 *Science* **285** 844–846). We have applied similar methods to investigate which

spatial scales encode apparent contrast of borders. Using standard psychophysical matching procedures, we measured the apparent contrast of a luminance border designed to appear as seen through an achromatic semitransparent patch, and of opaque borders obtained by reversing the polarity of the two surfaces of the patch. We systematically varied the reflectance of the transparent surface (Metelli's transparency), the viewing distance, and the size of the surface. The apparent contrast of the border decreased monotonically with progressive (ideal) high-pass frequency with a critical cut-off at 1 cycle deg^{-1} . With 2-octave ideal notch filtering, the maximum detrimental effect on apparent contrast was observed at about 1 cycle deg^{-1} . Both critical frequencies did not vary with reflectance, distances, or surface size, suggesting that apparent brightness of the border is determined by the frequency-tuned channel of 1 cycle deg^{-1} . Modelling the data with the local energy model (Morrone and Burr, 1988 *Proceedings of the Royal Society, Series B* **235** 221) at 1 cycle deg^{-1} confirmed the suggestion that this channel mediates apparent brightness for both opaque and transparent borders.

- **No evidence of polarisation sensitivity in the Japanese quail (*coturnix coturnix japonica*)**
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Many animals have sensitivity to the e-vector of linearly polarised light. This may assist in visually mediated behaviour such as navigation, signalling, and foraging. However, the evidence for polarisation sensitivity in birds is controversial. Experimental alteration of skylight polarisation patterns observable by migratory birds seems to alter their subsequent direction of departure on migration. In contrast, electrophysiological experiments have not revealed any polarisation-sensitive signals from birds' retinas. We tested whether or not Japanese quail can learn to discriminate objects differing in the pattern of linear polarisation of light reflected from their surfaces. We found that quail were unable to discriminate between objects whose surfaces had differing patterns of linear polarisation. In these patterns, the subcomponents either differed by 90° or were the same in their angle of polarisation. However, the birds were able to learn a control task of comparable difficulty. Quail, therefore, seem not to be able to use information in the polarisation pattern of objects to solve this foraging task. It is possible, however, that even if birds are unable to use polarisation sensitivity in tasks such as foraging, they may still be able to detect skylight polarisation patterns.

- **Effect of picrotoxin on the light responses of retinal ganglion cells and the local ERG**
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The effect of GABAergic blockade by picrotoxin on the activity of ganglion cells and the local ERG was investigated in perfused dark-adapted eyecups of frog (*Rana ridibunda*). Picrotoxin had diverse effects on the light responses of ganglion cells in contrast to its uniform potentiating effect on the amplitude of the b-wave and d-wave of the simultaneously recorded local ERG. Both potentiating and inhibitory effects on the activity of the ganglion cells were observed after the GABAergic blockade. In some cases ($n = 32$) the effects upon the ON and OFF responses were similar (both responses were potentiated or both were inhibited), but in the other ($n = 10$) the two responses were changed in a different manner. Picrotoxin influenced also the temporal characteristics of the ganglion cells responses. Some tonic OFF cells became phasic ones and in some phasic cells a late response appeared after the GABAergic blockade. In most cases ($n = 65$) the apparent cell type (ON, ON-OFF, or OFF) was not changed by picrotoxin, but in a few cases ($n = 4$) it was changed, because of appearance of a new type of response (ON or OFF). Our results indicate that GABAergic interneurons are involved in different networks in the inner plexiform layer of frog retina.

- **Nonlinearities in the interactions between receptive field centres and surrounds of LGN neurons**
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We studied whether a difference of Gaussians (DOG) model is sufficient to describe the receptive field (RF) structure of an LGN cell, by measuring the responses of LGN cells of the common marmoset (*Callithrix jacchus*) to stimuli that independently stimulated the RF centres and surrounds. A central stimulus was matched to the RF centre. An annulus mainly stimulated the RF surround. In the two stimuli, a sinusoidal luminance modulation was presented and the relative phase between the two was varied. From pairs of responses to these combined stimuli, the contributions of the RF centre and surround were extracted being the RF centre and

surround responses in the presence of a response in the other part of the RF. These were compared with responses to selective RF centre and surround stimuli. We found that the presence of a response in the RF surround does not influence the response properties of the RF centre. However, the presence of an RF centre response resulted in a phase-advanced RF surround response. This influence was stronger when the contrast in the surround stimulus was smaller. These data prove that some interactions between RF centres and surrounds cannot be described by a DOG model.

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- **Lateral interactions in the LGN cells and human visual perception**

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We studied interactions between centre and surround of receptive fields (RFs) of neurons in the lateral geniculate nucleus (LGN) and their consequences for human visual perception. Two series of experiments were performed. We recorded extracellularly from single cells in the LGN of common marmosets using combined stimuli that have a homogeneous central patch and a homogeneous surrounding annulus; luminance of the two was modulated sinusoidally in time with a variable relative phase. Responses of the cells depend significantly on the relative phase between the two stimuli. The psychophysically measured perceived flicker strength in the central stimulus also strongly depends upon the relative phase. Both physiological and psychophysical data can be described by a simple model in which the centre and surround responses are vector-added. Furthermore, in the two sets of data, the surround stimulus has to be presented phase-advanced to give a minimal response or a minimally perceived flicker strength, indicating that the RF surround response lags the centre response. Temporal frequency and surround contrast influence the surround phase lag in physiology and psychophysics in a similar manner. From these similarities we hypothesised that the physiological basis for flicker perception in the centre stimulus probably resides in the LGN.

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- **‘25 kadr’ and method of its detection in a display**

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An investigation of the flicker frequency in display images shows the presence of ecologically harmful frequencies, which coincide in several cases with alpha-rhythm and electroencephalogram frequencies (8–10 Hz). Measurements were taken on a setup that included a photoreceptor (fixed in front of the television screen or computer display), some videosynchronisation equipment, and real-time processing and saving of data on the hard disk of a PC for future processing. The obtained data allowed us to define temporal dependence of integral brightness of dynamic images and also allowed us to calculate changes in brightness from half-frame to half-frame and build a plot of changes in brightness. Flickers that produce visual discomfort are shown. There is good correlation between subjective evaluation and objective data. The presence of an inserted frame (the so-called ‘25 kadr’) was detected in several cases. In this case the setup recorded periodical changes of brightness, which were connected with the presence of a single frame insertions different in their contents from the main feature, as is demonstrated by us. Ecological danger of this kind of image is in the subconscious perception of these hidden insertions (especially for children).

- **Glycinergic system and retinal gain control—an ERG study**

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The participation of the glycinergic system in the retinal gain control was studied by comparing the response versus intensity functions of the turtle’s ERG b-wave and d-wave (ON and OFF response, respectively) before and during glycinergic blockade by strychnine. A potentiation by strychnine of the ERG ON and OFF responses was observed. The gain (dV/dI) and the contrast gain ($dV/d \log I$) were increased mostly in the lower stimulus intensity range. In this intensity range, the effect was greater in conditions of light adaptation than in conditions of dark adaptation. On the ground of the specific changes of the response versus intensity functions of the ERG responses the following conclusions about the role of the glycinergic system have been

made: (i) the glycinergic system participates in setting the gain and contrast gain of the ON and OFF responses in the distal retina in different conditions of background illumination; (ii) it may contribute to some extent to the adaptational changes in retinal gain when changing background illumination; (iii) the glycinergic system influences the contrast gain in the different parts of the $V(\log I)$ curves in such a way that a better approximation to linear function is achieved in the linear parts of these curves.

● **Detection and discrimination of texture modulations defined by orientation, spatial frequency, and contrast**

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We sought to determine whether the detection and identification of texture modulations are mediated by a common mechanism. On each trial two textures were presented, one of which contained a modulation in either orientation (OM), spatial frequency (FM), or contrast (CM). Observers were to indicate whether the modulated texture was presented in the first or second interval as well as the nature of the texture modulation. The results showed that for two of the three pairwise matchings (OM–FM and OM–CM) detection and identification performances were nearly identical, suggesting a common underlying mechanism. However, when FM and CM textures were paired, discrimination thresholds were significantly higher than detection thresholds. In the context of the filter-rectify-filter (FRF) model of texture perception, our results suggest that the mechanisms underlying detection are labelled with respect to their first-order input, ie the identities of these mechanisms are available to higher levels of processing. The misidentification of CM and FM textures at detection threshold is likely to be due to a failure of contrast normalisation between areas of different spatial frequencies.

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● **Contrast sensitivity characteristics of school-aged myopic subjects**

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In a previous study (Stoimenova, 1998 *Perception* 27 Supplement, 77) evidence was provided that grown-up subjects who have already developed school-aged myopia display lower contrast sensitivity to positive and negative contrast when stimulation is performed in the fovea. The purpose of the present study was to examine the quality of contrast sensitivity of the larger part of the central retina in the area with a radius of 5 deg around the centre of the retina. The monocular contrast thresholds for positive and negative contrast were measured in two groups of subjects: emmetropes and school-aged myopes. They were determined through a change of the letter contrast by applying the staircase method with a computer program and visual stimulus generator (Cambridge Research Systems). The stimuli were presented which extended 1, 2, and 5 deg up, down, left, and right of centre of fixation. The results show that myopic subjects in comparison to emmetropes have a smaller area with relatively high contrast sensitivity and this tendency of space reduction is adequate for the stage of myopia.

● **Contrast – contrast: brightness induction or lateral gain control?**

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Lateral gain control or brightness induction might explain contrast–contrast phenomena. To distinguish between these, we used a 2AFC staircase to measure the apparent contrast of a sinusoid (3 cycles deg⁻¹) in a circular (1 deg) patch, surrounded by a higher-contrast 8 deg surround (also 3 cycles deg⁻¹). The surround was either in-phase or opposite-phase with the centre, and either with an unmodulated gap separating them (1 to 30 min of arc; mean, max, or min luminance of surround) or not. With no gap, the surround in-phase with the centre yields strong suppression; it is negligible when out-of-phase. The presence of gap reduces both suppression and the phase effect. At 4 min of arc gap width, there is equal suppression both in in-phase and in opposite-phase conditions. Luminance of the gap has no effect on the strength of the suppression or phase effect. Induced brightness was also measured in equivalent spatial arrangements but with no modulation. Centre and surround luminances were either higher or lower than mean luminance. The gap was always set to the mean luminance. The brightness PSE of the centre patch was measured for a patch on a mean-luminance surround. The magnitude of brightness induction remains constant at gap widths less than 8 min of arc, then gradually declines. The different functions support lateral gain control over brightness induction.

- **Interattribute integration of contours**

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We can recognise the same shape, whether it is depicted by a difference in luminance, colour, or motion, although the visual system processes these attributes separately by their respective modules. How is such attribute independence secured in shape processing? We tested one of the most simple and plausible hypotheses: that contours of an input image are represented independently of the attribute. In the experiments on visual search for orientation, we presented bars composed of two squares defined by different attributes (light and red, for example), or bars composed of two squares defined by the same attribute (light and dark, for example). We found that search for orientation of bars composed of a motion-defined part and a luminance-defined or colour-defined part was very difficult, whereas it was rather easy if these parts were of the same attribute or defined by luminance and colour. This does not support the above hypothesis, and suggests that motion-defined and luminance-defined or colour-defined contours are encoded and processed to some extent through different pathways and then integrated.

TUESDAY
ORAL PRESENTATIONS**ILLUSIONS**◆ **The perceived value of π is 2.7**

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We investigated biases in the perception of the length of the circumference of a circle. Subjects observed stimuli comprising a line passing through the centre of a circle. The task was to decide if the line or the circumference of the circle was longer. The line-length was varied by means of a staircase in order to determine the PSE. Brief presentation times were used. Fixation was at the centre of the circle. The PSE for the line length was used to estimate the perceived value of π (veridically about 3.14) for each of fourteen naïve subjects. The across-subject mean was 2.7 (SD = 0.3). Therefore subjects underestimated the line length required to make it equal to the circle circumference. The extent of the misperception was not significantly related to the level of mathematical education reached by the subjects or to whether they claimed to use cognitive strategies to do the task. Similar results were obtained for eccentric fixation. We believe that this effect originates at a relatively high level of the visual system. It is rather surprising that simple geometrical shapes such as a circle and a line show biases of this kind, which echo the Piagetian conservation failures exhibited by children.

◆ **'Illusory contours' in primary visual cortex: illusory or contours?**

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Neurons in V1 and V2 respond to an 'illusory' contour arising from the juxtaposition of two gratings 180° out of phase. Such responses are generally thought to be caused by nonlinear mechanisms in the receptive field. We wondered whether they could arise from simple linear mechanisms. We constructed a model simple cell with a linear kernel and explored its response to the edge produced by abutting gratings. The cell did respond to the illusory edge though not as strongly as to a luminance edge or gradient. The response varied with the spatial frequency of the gratings that comprised the stimulus and their phase in relation to the receptive field. We compared the responses of model cells with those of single neurons in V1 of anaesthetised macaques. In the manner predicted by the model, responses of real neurons varied with the phase and spatial frequency of the gratings that defined the edge. Furthermore, the responses of cells to the abutting gratings were largely predicted by their responses to a luminance edge. The results suggest that responses of neurons to 'illusory' contours can be understood without resort to nonlinear subunits or feedback from higher cortical areas.

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◆ **Illusory motion from opposite-polarity form cues: it's not a jitter bug**

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It has, for a long time, been known that human observers can extract form from motion cues. This has been taken as evidence that there are interactions between extrastriate motion and form-recognition processes that are otherwise thought to be independent. More recently it has been demonstrated that a set of serially presented form images can generate the perception of coherent motion even when there is no coherent motion signal (Ross et al, 2000 *Current Biology* 10 679–682). This observation of motion-from-form has been interpreted as evidence for return projections between form and motion processing mechanisms. Here we describe a new visual illusion that gives a motion percept from a single presentation of a stationary form stimulus. That is, unlike apparent motion and motion-from-form, the illusory motion we describe does not require a serial presentation of images. We demonstrate how form images generated in accordance with specific parameters elicit the perception of coherent but ambiguous motion at stimulus onset and offset. We have investigated the parameters affecting the perceived motion and argue that the effect is mediated by form processing mechanisms beyond the striate cortex.

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◆ **A new flashing anomalous colour contrast illusion**

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We studied a striking effect, flashing anomalous colour induction, arising from the interaction between a gray central disk and a coloured annulus, surrounded by black radial lines. The complementary colour is induced in the central disks, and with eye movements one experiences distinct scintillating flashes. Fourteen naïve subjects used magnitude estimation to scale the strength of induced flashing colour. The contrast of the gray inner disks; the number, length, width, colour, and contrast of the radial lines; as well as width, contrast, and colour of the ring were systematically varied. We found that flashing anomalous colour contrast: (i) appears mostly in peripheral vision; (ii) induces a strongly saturated complementary colour; (iii) appears as a coloured light superimposed but separated from the gray disks; (iv) appears unusually white when the disks inside the rings are white; (v) appears only in the presence of the radial lines; and (vi) lacks scintillation with chromatic radial lines. Flashing anomalous colour contrast is a new illusion of complementary colour induction, different from simultaneous colour contrast, and cannot be simply accounted for by double-opponent cells.

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◆ **Emmert's flaw**

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Should Emmert's law say afterimages increase in size linearly with real or with apparent distance? Are afterimages scaled with size constancy? How are they related to knowledge of background objects? We offer a tentative analysis of these complex issues and demonstrate an experimental technique.

MODELLING

◆ **A gain-control network model of the dynamic motion aftereffect**

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To develop an explanatory model of the dynamic MAE we modified a successful network model of the static MAE (Grunewald and Lankheet, 1996 *Nature* **384** 358–360) and combined it with feedforward automatic gain controls. The resulting model is analysed mathematically and studied by simulation in MatLab. This suggests an (almost) linear relation between dynamic-MAE-duration T_d and the ratio of nulling threshold S_0 (quantified as luminance signal-to-noise ratio or LSNR) to direction discrimination LSNR threshold S_d . To test the proposed model we determine S_0 and S_d psychophysically, with a Quest staircase procedure, as a function of adaptation speed and adaptation strength (also quantified as LSNR value). T_d is measured separately for the same subjects and the same variables and correlated with the ratio S_0/S_d . In all experiments, moving random-pixel arrays (Julesz patterns) were used. The model predictions have been found to describe the psychophysical results of all subjects very well. Thus, a reliable psychophysical measure like S_0/S_d can replace the rather subjective and noisy measure T_d . Our model is a valuable tool of thought that suggests several new experiments on the speed, orientation, and space–time tuning properties of the gain controls that are responsible for MAEs.

◆ **Modelling the temporal aspects of the McCollough effect: Simple decay, drug effects, and pre- and post-induction interference**

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McLoughlin and Savoy (1995 *Perception* **24** Supplement, 94) presented a simple model that was capable of quantitatively accounting for some fifteen monocular and binocular variants of the McCollough effect (ME) (McLoughlin and Savoy, 2002 *Vision Research* submitted; Savoy and McLoughlin 2002 *Vision Research* submitted). The model, based on a learning mechanism between achromatic oriented and chromatic unoriented units, was defined by a set of simple

differential equations and is easily applied to the study of the temporal aspects of the ME. The same model and parameters have been used to account for a wide variety of temporal aspects of the ME, including the standard decay or extinction profile and pre- and post-induction interference effects. Results of recent simulations of the effect of pre-viewing achromatic stimuli prior to ME induction (Skowbo, 1979 *Perception & Psychophysics* **26** 105–107; 1988 *Perception & Psychophysics* **44** 295–303), the effect of post-viewing achromatic stimuli after ME induction (Skowbo and Clynes, 1977 *Perception & Psychophysics* **21** 180–182; Skowbo, 1988), and the effect of various drugs on the initial strength and decay of the ME (Byth et al, 1992 *Psychopharmacology* **106** 75–84) are presented.

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◆ **Template model for blur coding: the role of early nonlinearity in edge segmentation**

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We describe a template model for perception of edge blur and identify a crucial early nonlinearity in this process. The main principle is to spatially filter the edge image to produce a 'signature', and then find which of a set of templates best fits that signature. Psychophysical blur-matching data strongly support the use of a second-derivative signature, coupled to Gaussian first-derivative templates. The spatial scale of the best-fitting template signals the edge blur. This model predicts blur-matching data accurately for a wide variety of Gaussian and non-Gaussian edges, but it suffers a bias when edges of opposite sign come close together in sine-wave gratings and other periodic images. This anomaly suggests a second general principle: the region of an image that 'belongs' to a given edge should have a consistent sign or direction of luminance gradient. Segmentation of the gradient profile into regions of common sign is achieved by implementing the second-derivative 'signature' operator as two first-derivative operators separated by a half-wave rectifier. This multiscale system of nonlinear filters predicts perceived blur accurately for periodic and aperiodic waveforms. We also outline its extension to 2-D images and infer the 2-D shape of the receptive fields.

◆ **Computational analysis of stimulus visibility, masking effectiveness, and reaction time in visual masking**

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Previous studies showed that the visibility and the masking effectiveness of a mask M1 can be modulated by a second mask M2. We performed a computational analysis of the RECOD model to investigate potential mechanisms underlying this modulation. In the simulation, the stimulus onset asynchrony (SOA) between the target (T) and M1 was set to a value producing strong suppression of T's visibility and the SOA between M1 and M2 was varied. In quantitative agreement with data, the simulation showed a double dissociation between M1's visibility and masking effectiveness. For negative SOAs between M1 and M2, the masking effectiveness of M1 was reduced, while its visibility did not change significantly; on the other hand, for SOA values >60 ms, the visibility of M1 decreased significantly without a concomitant change in its masking effectiveness. According to the model, M1's visibility and masking effectiveness are correlated with its sustained and transient activities, respectively. The double dissociation occurs because M2 suppresses either the transient (for negative SOAs) or the sustained activities of M1 (for positive SOAs), but not both. This observation led to a second simulation where reaction time to T increased in paracontrast. This novel prediction received support from our recent data.

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◆ **A program for interpreting line drawings**

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We readily interpret line drawings as 3-D objects. One way of understanding this ability is to build a computer program that emulates human performance. Here, a new program is presented which can interpret a wide range of line drawings of 2-D and 3-D objects, including those with occlusion and transparency. The domain of interpretation is much wider than the line-labelling 'microworlds' (eg Clowes, 1971 *Artificial Intelligence* **2** 79–116; Kanade, 1980 *Artificial Intelligence* **13** 279–311). The program is explained, its scalability explored, and its relevance to understanding phenomena like subjective contours and contour path extraction is discussed. The program structure is similar to (but more general than) that described in Liu and Lee (2001 *IEEE Transactions on Pattern Analysis and Machine Intelligence* **23** 1106–1119). The program operates by finding a set of possible surfaces bounded by the lines in the image, then selecting a

maximum-likelihood subset of those surfaces which accounts for all the lines in the image. The use of likelihoods leads automatically to a parsimonious interpretation, because large subsets tend to have a lower likelihood (given by the product of the likelihood of the component surfaces) than small subsets. Finally, the selected surfaces are clustered into objects and assigned 3-D slant and tilt estimates. A MATLAB implementation is available.

BINOCULAR VISION

◆ **Stereopsis: the binding of depth to visual directions rather than to patterns**

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When the level of correlation between the images presented to the left and right eye is sufficiently high, we perceive depth during the viewing of random-dot stereograms. When the level of correlation is low, we experience rivalry between the images and no depth. To investigate the interaction between processes that underlie stereopsis and rivalry, we designed dynamic random-dot stereograms in which we periodically alternated the level of correlation between the images. In these stereograms, our subjects perceived sustained depth without being able to see the disparity-inducing patterns. Instead, they perceived rivalrous patterns on the surfaces of the depth figures. Since these figures were invisible in the monocular images, their depth and shape must have been induced by binocular disparity. This result shows that disparity-induced depth is not necessarily bound to the disparity-inducing patterns. We suggest that stereopsis is the result of a neural architecture in which disparity-induced depth is bound to visual directions ('where') rather than to patterns ('what'). This theory contradicts two current theories about how binocular signals reach the level of conscious perception.

◆ **The influence of cyclovergence on unconstrained stereoscopic matching**

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In order to perceive depth from binocular disparities the visual system has to identify matching features on the two retinæ. Normally, the assigned depth is unambiguously determined by monocularly visible matching constraints. The assigned depth is ambiguous when matching is unconstrained, such as when we view an isolated long oblique disparate line. Recently we found that in order to perceive a depth probe at the same depth as the oblique line, the probe needs to have the same horizontal disparity as the line [ie matching occurs along horizontal 'search-zones' (van Ee and Schor, 2000 *Vision Research* **40** 151–162)]. Here we examined whether the depth probe disparity in unconstrained matching of long lines is influenced by cyclovergence, by cyclorotation between stereogram half-images, or by combinations of the two. We measured retinal rotation ($>6^\circ$ in cyclovergence conditions). In four subjects we found that in those conditions in which the retinal images were similar (when cyclovergence was just as much as cyclorotation) assigned depth was similar too, ie independent of, cyclovergence. Thus, the assigned depth of the test line seems to be determined solely by the retinal test-line orientation, rather than the test-line orientation in the stereogram.

◆ **Combining information from vertical disparities and vergence to estimate distance to fixation**

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Porrill et al (1999 *Nature* **397** 63–66) described a method for pooling vertical disparities using robust Bayesian statistics. They reported an induced-effect experiment showing a predicted bifurcation point in pooling conflicting information from two populations of points, suggesting that human vision implements the method. Aranaz et al (2000 *Perception* **29** Supplement, 50) also found the predicted bifurcation using scalings which simulate a fixation distance d . In the present experiment we studied pooling information about d from vergence and mixtures of cues. Vergence was manipulated by varying the horizontal positions of the two stereo-halves of large-field random-dot stereograms (cf Rogers and Bradshaw, 1995 *Perception* **24** 155–179). The subject's task was to null the perceived curvature caused by the mixture of cues by adjusting horizontal disparities, from which were inferred the prevailing estimates of d . As d s signalled by two populations became increasingly dissimilar, responses tended towards the d most in keeping with vergence. The results are analysed as reflecting a maximum-likelihood d -estimation process in which cue weights are a function of the variances of measurements based on those cues. This leads to the conclusion that vergence is a much noisier cue to d than vertical disparity.

◆ Evidence for spatial-scale interactions in human stereopsis

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We investigated temporal properties of stereoscopic depth perception at different spatial scales. We used large dynamic random-dot stereograms consisting of repeated presentation of a correlated image pair interleaved with an anticorrelated image pair. We varied the coarseness of the dots. By alternating stereograms containing dots at the same scale (coarse or fine) and also using images containing coarse dots alternated with images containing fine dots we varied interocular correlation at different scales as a function of time. Stereopsis was examined in a forced-choice depth-detection task. Our results indicate that: (i) temporal properties of stereopsis are independent of scale when correlated and anticorrelated images are of the same spatial scale; (ii) anticorrelated images containing coarse dots strongly obstruct stereopsis at a fine spatial scale; (iii) anticorrelated images containing fine dots hardly affect stereopsis at coarse spatial scales. The experimental results are well described by a model of depth detection that is based on a coarse-to-fine strategy. This study provides experimental evidence for a hierarchical organisation of spatial-scale channels in human stereoscopic vision based on neural interaction instead of vergence eye movements as proposed by Marr and Poggio (1979 *Proceedings of the Royal Society of London, Series B* **204** 301–328).

◆ ‘Dipper function’ within, but not between, cues for depth and lateral motion

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The presence of a ‘dipper function’ for an increment threshold is often attributed to a stage of summation followed by a nonlinearity. Here we probe combinations of depth and lateral motion to discover whether these cues share a common summation stage. On each trial, a bright vertical bar oscillated at 3 Hz for 1 s, flanked by two stationary reference bars presented at zero disparity. Using a two-interval forced-choice paradigm, we measured increment thresholds for the detection of (i) lateral and (ii) depth motion amplitude in the presence of a pedestal oscillation of either (a) lateral or (b) depth motion. Thus, when both lateral and depth cues were applied, the target line oscillated along a diagonal path in depth.

Threshold increments followed a dipper function when plotted against pedestal size for the same cue (eg lateral increment threshold against lateral pedestal amplitude). Minimum increment thresholds occurred at pedestal amplitudes approximately equal to the baseline detection level for that cue. We found no dip in the threshold function when increment thresholds for one cue were tested at different pedestal values for the other cue. The results indicate that independent visual mechanisms may sustain the detection of lateral motion and motion-in-depth.

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FACE PERCEPTION

◆ Representation of geometric face information by principal components

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We have recently devised a novel class of synthetic faces described in front or 20° side views by 37 geometric parameters each. Synthetic faces are also bandpass filtered to the optimal spatial-frequency range for discrimination. Using Gram Schmidt orthogonalisation, we have constructed 4-dimensional ‘face cubes’ and have shown that discrimination thresholds are lowest near the mean face for each gender. To determine how the geometric information in synthetic face stimuli is analysed by the visual system, we have also constructed 4-dimensional face cubes using sets of 4 principal components for the axes. Note that this is not a principal-component (PC) analysis of gray-scale images but rather of the geometric information describing synthetic faces. For all subjects PC discrimination thresholds average 2.4 times lower (better) than thresholds for face cubes derived from individual faces. Furthermore, this difference in thresholds can be predicted on the basis of PC amplitudes in individual faces. The relationship between these results and independent-component analysis will also be considered. These experiments provide strong psychophysical evidence that the geometric structure of faces is represented by principal components.

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◆ **Amodal completion in a matching task of face recognition**

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If a partially occluded face has been learned, which will be recognised better, the identical stimulus or the intact face? We studied the degree to which the representation of an object completes itself behind occlusion. We used a same–different matching task where perceptual completion was less expected than template matching, since the faces were identical in a ‘same’ trial. In each trial, the stimulus sequence was as follows: the first image (1 s), mask (0.2 s), fixation (0.05 s), the second image (0.5 s), mask (0.2 s), and fixation. Subjects decided whether the two faces were of the same person. We used random dots as partial occlusions with five levels: 20%, 30%, 40%, 50%, or 60% for each face image. In a control experiment, five levels of fence occlusion were used. We found that when the occlusion was 60% for the first image, 50% (not 60% or 10%) occlusion of the second image yielded the peak performance [d' ($n = 27$, $p = 0.008$) and hits alike]. In contrast, with fence occlusion, the hits peaked whenever occlusions were identical, strongly suggesting template matching. It follows that perceptual completion was apparent even when template matching was presumably dominant. The spatial extent of this completion, however, was limited.

[Supported by the National Eye Institute, USA.]

◆ **Applying ‘bubbles’ to understand the face information driving event-related brain potentials**

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Since the 1930s when ethologists first addressed it, the ‘stimulus signal’ has been one of the most fundamental issues in recognition. A stimulus signal is the portion of the stimulus that elicits the organism’s response—where the response can range from a behaviour to a physiological correlate. Here, we searched for the stimulus signal of the N170 (event-related brain potential negative over lateral posterior temporal cortex with a latency of about 170 ms) when observers resolved a face-gender categorisation over 2000 trials. Each trial started with the presentation of one neutral face (from five males and five females) sampled with Gosselin and Schyns ‘bubbles’ (Gosselin and Schyns, 2001 *Vision Research* **41** 2261–2271). We recorded brain electrical activity from 32 channels while observers performed the task. Using a dipole-source projection method, we measured the N170 amplitudes in single trials to produce a distribution of the amplitudes. We discretised distribution into ten amplitude clusters distributed around the mean. For correct, non-artifact trials, we added in each cluster the information samples eliciting this amplitude. By collapsing the distribution around the mean, we produced a classification image that reveals the information separating small and large N170 amplitudes. This information is the stimulus signal driving N170 in this task: the eyes of the face.

◆ **Non-conscious recognition of famous faces: better the devil you know?**

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Non-conscious face recognition was investigated in neurologically intact participants using very brief (17 ms) masked stimulus presentation to prevent awareness of facial identity. Faces were presented in simultaneous pairs of one famous and one unfamiliar face, matched on physical characteristics. The required response was to select the famous face in each pair. In experiments 1 and 2 we found that participants who were at chance in discriminating famous from unfamiliar faces were more likely to select the famous face when it belonged to a celebrity subsequently rated as good rather than evil. When the data from experiments 1 and 2 were combined, the faces of celebrities rated as evil were selected below chance. In experiment 3 we obtained a similar result in a within-items analysis of 45 famous faces: the famous face in each pair was selected more often by participants who liked rather than disliked the celebrity. Experiment 2 also provided evidence of perceptual defence, with faces of evil celebrities generating weaker (and consciously unrecognisable) visual impressions than unfamiliar faces. The results suggest that facial identity is recognised pre-consciously, and that aversive processes are invoked towards celebrities regarded as evil.

◆ Motion perception of gaze shift

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Performance in stationary gaze perception is not affected by viewing distance (Sato and Matsuzaki, 2001 *Perception* 30 Supplement, 34). This suggests gaze perception is limited by parameters relative to object size rather than absolute spatial parameters. In this study, we extended this hypothesis to dynamic gaze perception. Stimuli consisting of digital photos of persons having ± 6 deg gaze shifts around centre in 12 min of arc steps were prepared. These photos were presented in real size on a CRT screen and viewed from a distance of 114 cm. Motion threshold for gaze shift (two-frame apparent motion) was measured around the central and 6 deg offset gaze positions by the method of constant stimuli. The threshold obtained was about 30 min of gaze shift, regardless of the position. This threshold gaze-angle shift corresponds to a 3 s of arc shift of iris edge. So, the motion performance for gaze shift, if we assume it is edge-based, involves hyperacuity and accords with regular motion acuity. However, when the viewing distance was halved to 57 cm, threshold did not change as much as expected from visual angle. Therefore, these results support our previous results for stationary gaze perception that gaze perception is based on relative rather than retinal parameters.

[Supported by HFSP]

SYMPOSIA

BINOCULAR VISION: A SYMPOSIUM IN HONOUR OF THE 200TH ANNIVERSARY OF THE BIRTH OF SIR CHARLES WHEATSTONE

► Wheatstone's vision

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Charles Wheatstone (1802–1875) transformed not only our vision of pictures but also our picture of vision. His invention of prism and mirror stereoscopes in the early 1830s opened a new world for the study of binocular vision. With their aid, methods of physics could be applied to laboratory investigations of spatial vision. Wheatstone established that dissimilar pictures, when viewed in the stereoscope, produce the appearance of depth, and he conducted a series of systematic manipulations of the figures in order to discover the nature of the relationship. Some years later he described an adjustable mirror stereoscope and a pseudoscope for reversing disparities. The main purpose of these was to extend the range of conditions under which the two eyes could be stimulated. Wheatstone used the stereoscope with adjustable arms to vary the changes produced when approaching a solid object (retinal size, convergence, accommodation, and disparity). He applied the pseudoscope to reverse the normal relations between monocular and stereoscopic cues to depth, and remarked on the difficulty of perceiving reversals of relief with the pseudoscope and the illuminating conditions that are necessary for such reversal. Historically, more attention has been vested in the instrument, the stereoscope, than in the observations Wheatstone made with it. This relates first to the colourful disputes that have raged regarding the priority of its invention. A second factor is that the fusion of the stereoscope with photography provided a popular platform for the instrument, and many versions of it were subsequently patented.

► Charles Wheatstone and the cardboard cut-out phenomenon

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The 1830s saw not only Wheatstone's demonstration of the stereoscope but also the development of photography by Fox Talbot, Daguerre, and others. Commercially produced stereo photographs were already available by the early 1850s. Observers of stereo photographs have frequently noted that the 3-D impression of the depicted figures and objects is often incorrect—consisting of a number of separated depth planes rather than the correct volumetric structures. Why should this be? Howard and Rogers [1995 *Binocular Vision and Stereopsis* (New York: Oxford University Press)] speculated that this 'cardboard cut-out' phenomenon was due to the fact that the distances signalled by convergence and accommodation are typically much smaller than those of the original scene. To test this speculation, I have systematically manipulated the (i) convergence distance, (ii) accommodation distance, (iii) differential perspective information (vertical disparities), and (iv) angular size of the stereo images (compared with the original scene), and measured the effect of these manipulations on the perceived layout and 3-D shape of stereo images using both matching and nulling techniques. Overall, the results suggest that the cardboard cut-out phenomenon is a product of cue conflicts and that spatial layout and the volumetric properties of objects are seen correctly when these conflicts are minimised.

► **Wheatstone's dominant observations on binocular rivalry**

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With his invention of the stereoscope, Wheatstone convincingly showed that right and left eye views could harmoniously blend into a stable, three-dimensional impression of the visual world; the synergistic interaction implied by stereopsis led Wheatstone to reject the idea that ordinarily we see with only one eye at a time. At the same time, Wheatstone also convincingly showed that vigorous, unrelenting conflict was instigated when left and right eyes held radically different views—this conflict was evidenced by fluctuations in visual awareness over time. This phenomenon, binocular rivalry, had been noted in earlier writings, but it is Wheatstone who deserves credit for bringing this fascinating outcome to the foreground of perceptual science. In his classic 1838 paper, Wheatstone commented on several key features of rivalry, including the influence of stimulus strength on predominance, the piecemeal nature of transitions in perception during rivalry, and the inability to control dominance by will-power. Wheatstone's account of rivalry doubtlessly played a key role in stimulating the thinking of later giants in the field (Helmholtz, James, Sherrington) who championed rivalry as a visual phenomenon of broad importance.

► **Cortical coding of binocular depth**

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Wheatstone demonstrated the sufficiency of binocular information to create a perception of depth, when he invented the stereoscope. He also debated vigorously with Brewster the insights that may be gained from perceptually reversible figures, such as the Necker cube. I review recent progress in the physiological processing of binocular information in striate and extrastriate cortical areas from single-unit recording studies in awake behaving primates and fMRI in human subjects. Extrastriate cortical areas prove to display a rich set of phenomena that in many cases parallel the perceptual properties of binocular vision. Among the most significant of these are neuronal events in cortical area V5/MT, which reflect closely the perceptual responses of subjects during the viewing of reversible figures that contain ambiguous structure-from-motion. [Supported by the Wellcome Trust.]

► **Unpaired image regions: a Wheatstonian perspective**

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Wheatstone showed that it is a visual advantage to have the two different perspective views of a scene that binocular vision provides. Brewster questioned this saying that binocular vision has the disadvantage of producing monocular regions that fail to unite with the binocular regions. It is only recently that the way occlusion/camouflage configurations generate monocular regions and the manner in which they unite with binocular regions have been systematically studied. Although Wheatstone did not himself explore this issue, modern research extends his idea that the brain is capable of interpreting differences in perspective views to include the differences in monocular details as well as width disparities resulting from occlusion. The role of monocular regions and features in the perception of spatial layout is summarised and some new principles of binocular processing involving these regions are briefly discussed. These include the ability of monocular features to suppress disparity processing and the ability of unpaired background regions to generate surface splitting, very precise depth processing, and stereo adaptation in the absence of a disparity signal. Stereoscopic theory must in future deal with a broader picture in which disparity-based depth can no longer be regarded as a unique and modular process.

EXAGGERATION AND VISUAL COGNITION

► **Averages and extremes in face perception**

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Caricatures, which exaggerate the distinctive features of a face, are easy to recognise, but hard on the eye. These two effects suggest that the visual system might code faces as deviations from an average face, which is also an ideal face. Here we explore the role of norms (averages) in face perception by examining aftereffects of adaptation to distorted faces. We show that adaptation to a particular distortion shifts what looks normal (average) in the direction of the adapting distortion (Webster and MacLin, 1999 *Psychonomic Bulletin & Review* 6 647–653), and that this is accompanied by a corresponding shift in what looks most attractive. The aftereffects occur

when the test faces are rotated 90° relative to the adapting faces (from 45° left to 45° right, or vice versa) suggesting that they result from adaptation in high-level neurons. We interpret the shift in optimal attractiveness that accompanies the shift in what is perceived as average as strong evidence that average faces are attractive.

► **Exploring face representation in humans and monkeys by using high-level aftereffects**

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As a first step toward investigating the neural encoding of faces and other complex objects, we examined the effects of visual adaptation on the perception of human faces. We found that following a few seconds of exposure to one face, the perceived identity of a second face was systematically distorted along a specific trajectory in multidimensional 'face space'. This trajectory passed through the central tendency of all faces, and its direction thus defined a particular identity. The results suggested that the visual system considers the average prototype face to be a reference point in its representation of faces, and led us to speculate that neural decoding of faces is a fundamentally comparative process. Such a scheme might constitute a fast and economical storage strategy for the brain to contend with a myriad of very similar shapes. With the aim of investigating this hypothesis more directly by neurophysiological methods, we recently trained a monkey to perform the same task, again with human faces. We found that, while the monkey's identification thresholds were slightly higher than the mean threshold for humans, his perception was affected by adaptation in exactly the same way as that of the human subjects. [Supported by the Max Planck Society.]

► **Going to the other extreme! Investigating recognition of emotional expressions with anti-faces rather than caricatures**

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Exaggerating the differences between an example face and a prototype creates a caricature. The same differences can be applied to the prototype in the opposite direction to create an 'anti-face'. Leopold et al (2001 *Nature Neuroscience* 4 89–94) report that adaptation to anti-faces creates high-level visual aftereffects, which aid recognition of face identity. Here the effect of adaptation to anti-faces on the recognition of emotional expressions was investigated. Anti-face expressions were constructed to have the opposite feature configuration and textural properties of particular expressions (anger, disgust, fear, and sadness). During testing, subjects adapted to anti-face expressions for 3 s before being presented with a facial expression to categorise. Adaptation to anti-face expressions caused the subsequently presented corresponding expression to be recognised more readily. This facilitatory effect was robust to changes in the identity of the face between adaptation and categorisation, to backwards pattern masking and to delay between the adapting stimulus and the expression to be identified. The results are interpreted as reflecting long-term suppression of temporal cortex neurons tuned to specific facial configurations.

► **Using the principles of facial caricature to exaggerate human motion**

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The ways in which we move our faces and bodies are the source of much biologically important information. Such movements can be exaggerated by extending techniques developed for static facial caricature into the temporal domain. Spatial exaggeration of movement is accomplished by first time-normalising the sequences to be exaggerated and then exaggerating the differences between individual frames and an average frame. We can also exaggerate the temporal properties of movement by reversing and extrapolating the time-normalisation step. Previous findings from a variety of domains where exaggeration has been shown to enhance the perception of task-relevant information are reviewed, together with new data showing that spatial exaggeration of emotional utterances relative to an averaged utterance can enhance their perceived happiness, sadness, or anger. Conversely, it is argued that exaggerating emotional or other individual differences may actually interfere with the recovery of information common to all the sequences being averaged, in this case the lexical content. Lastly, motion exaggeration, like facial caricature,

may reflect general underlying principles involved in the encoding and discrimination of biological movement, an as yet poorly understood process.
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◆ **Spatiotemporal exaggeration of complex biological movements**

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Exaggeration techniques are an excellent tool for investigating the representation of complex visual stimuli. In particular, they can help explore the notion that such stimuli are encoded as elements within continuous multidimensional perceptual spaces. For example, experimental evidence supporting this idea has been provided by the caricature effect for faces (eg Rhodes et al, 1987 *Cognitive Psychology* **19** 473–497; Benson and Perrett, 1994 *Perception* **23** 75–93). Traditionally, exaggeration techniques have been applied to static stimuli. However in everyday life we are mostly confronted with moving stimuli. Can complex-motion stimuli, such as biological movements, also be represented in continuous multidimensional spaces? Several methods have recently been developed which suggest that this is possible. These methods can be used to produce spatiotemporal caricatures. The aim of this contribution is twofold. First, we give an overview of these various spatiotemporal exaggeration methods. Second, we present a new method for the morphing and exaggeration of long complex sequences of facial expressions using photorealistic head models. In addition, preliminary data are shown which demonstrate the effect of spatiotemporal exaggeration on the ability to discriminate between complex individual facial-motion patterns.

ORAL PRESENTATIONS

3-D SPACE

◆ **When rocking motion turns into motion transparency**

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A powerful demonstration was constructed by Gerbino showing the difference between local and global motion processing [Gerbino and Berneti, 1984 *Perception* **13**(1) A38; Gerbino et al, 1998 *Perception* **27** Supplement, 188]. The stimulus consists of random dots that are individually moving back and forth over very short distances. When all the dots move in phase, a pattern moving back-and-forth is perceived. However, if the dots are moving with a random initial phase, perfect motion transparency is seen. The local motion of each individual dot can then only be perceived by directing attention to the dot. We determined the transition phase for which observers rated the stimulus as either a rocking pattern or motion transparency, by manipulating the phase distribution of the dots. This phenomenon has an interesting implication: it demonstrates that surfaces are extracted by integrating local motions over space and time at the cost of the representation of individual motion elements. We suggest that, under these conditions, dots lose their identity and therefore conscious access in favour of a higher representation of surfaces (see also Treue et al, 1995 *Vision Research* **35** 139–148). This identity can only be recovered by directing attention.

◆ **A correspondence-noise limitation for coherent and transparent motion**

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Correspondence noise is a known limitation in recovering coherent motion, demanding motion integration (Barlow and Tripathy, 1997 *Journal of Neuroscience* **17** 7954–7966). We compared the effect of correspondence noise on coherent motion with that for transparent motion, which requires both integration and segmentation of motions belonging to different surfaces.

In a 2AFC speed-discrimination task, we presented opposite-direction random-dot stimuli at a range of dot densities (1%–32%). One motion was the standard (2.63 deg s^{-1}), the other the target (5.26 deg s^{-1}). We compared human performance with that of the theoretical ideal observer to compute the efficiency for coherent and transparent motion. We found that efficiency decreased as dot density was increased, in both conditions. In addition, there was an overall cost in efficiency for speed discrimination of transparent motion. Efficiencies approached a maximum of 10%. The similar dependence on dot density for coherent and transparent motion supports a correspondence-noise-sensitive mechanism underlying motion integration. However, there is an additional cost in efficiency for motion segmentation. This additional cost can be accounted for

by inhibition between motions of opposite directions, a mechanism recently identified in human MT+ (Heeger et al, 1999 *Journal of Neuroscience* **19** 7162–7174).
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◆ **Viewing geometry and combining disparity and texture-gradient information**

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We examined how the visual system combines disparity and texture gradients to recover surface slant and tilt under different viewing conditions. Several investigators have argued that combined stereo-texture estimation can be modeled as a weighted combination: $S_c = w_t S_t + w_s S_s$, where S_t is the texture slant estimate, S_s is the stereo estimate, w_t is the texture weight, w_s is the stereo weight, and $w_s + w_t = 1$. To exploit this cue-combination scheme, the visual system must know how the reliabilities of disparity and texture gradients vary with viewing geometry. Reliability of disparity varies with viewing distance, slant, tilt, and azimuth. Reliability of texture varies with slant, but in the opposite direction from the reliability of disparity. We first measured reliability of texture and disparity gradients as a function of distance, slant, tilt, and azimuth. We used these results to determine optimal cue weighting for the various viewing parameters. To determine if the visual system follows an optimal weighting strategy, we used a cue-conflict paradigm. Results can be predicted by linear weighted summation and indicate that the visual system uses the reliabilities of disparity and texture gradients appropriately with changes in viewing geometry. [Supported by National Institutes of Health.]

◆ **Conditions where motion parallax supplements shape-from-texture**

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On the basis of contributions to 3-D shape perception in perspective images, there are three classes of surface textures: (i) textured images that contain signature patterns of visible orientation modulations convey qualitatively veridical, but metrically imprecise, shapes; (ii) when the requisite orientation modulations cannot be extracted from texture variations, frequency modulations are used as distance cues, leading to qualitatively distorted 3-D percepts; (iii) surfaces appear flat if even frequency modulations cannot be extracted from the image. For vertical sinusoidal corrugations, we used horizontal translation, rotation around the horizontal axis, and rotation around the line of sight, to examine how motion parallax supplements the 3-D information provided by each texture class. (i) Motion does not provide supplemental metric information for images containing the requisite orientation modulations. (ii) Under horizontal translations, motion parallax supplements visible static frequency modulations and leads to qualitatively veridical percepts. This required motion correspondence: veridical shape was not perceived if uncorrelated statically correct frequency modulations were presented in successive frames. (iii) In images without requisite orientation and frequency modulations, surfaces appeared flat during all motions. Shape-from-motion thus supplements shape-from-texture only for textured surfaces whose images contain frequency modulations but not the requisite orientation modulations, eg textures with isotropic frequency spectra.
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◆ **Errors in perceived direction of slant as a function of surface texture anisotropy**

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Slanting a planar surface produces two projective gradients: a gradient of compression and a gradient of linear perspective (convergence). Gillam (1968 *Journal of Experimental Psychology* **78** 299–305) showed that in monocular vision a gradient of compression is far less effective than linear perspective in giving an impression of slant, and this has recently been confirmed by others. Furthermore, for an anisotropic surface texture, the mathematical strengths of the compression and convergence gradients vary in inverse relation to each other as the orientation of the surface texture anisotropy is varied (in the plane of the surface) relative to the orientation of the axis of slant of the surface. These observations led us to predict that, for anisotropic surface textures, the direction of slant of a surface may be substantially misperceived in some circumstances, with the direction and amount of error depending on the angular relation between the axis of slant and the orientation of the texture anisotropy. We have explored and verified this prediction. We found little systematic error in perceived direction of slant when an isotropic surface texture was rotated in the plane of the surface, but with a strongly anisotropic surface

texture we found substantial systematic errors. Moreover, combining the two textures produced intermediate results.

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CONTRAST

◆ Contrast conservation in human vision

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We studied the temporal and spatial characteristics of contrast perception with briefly presented suprathreshold gratings, plaids, noise, and natural scenes that changed suddenly halfway through their presentation. These component stimuli were of fixed contrast and variable duration, and observers matched them to static stimuli of variable contrast and fixed duration, in a 2AFC paradigm. As duration increased, the matching contrast of the changing stimuli approached an asymptote. When the apparent contrasts of the component stimuli equalled their physical contrast (eg gratings), the asymptotic matching contrast equalled the sum of the two physical contrasts. When the apparent contrast of a stimulus differed from its physical contrast, eg plaids (Georgeson and Shackleton, 1994 *Vision Research* **34** 1061–1075), the asymptotic matching contrast equalled the sum of the apparent contrasts, not that of the physical contrasts. However, unlike thresholds, these matches were unaffected by changes of orientation (90°) or phase reversal, in the case of gratings; or by substitution of an entirely new stimulus of the same contrast, in the case of noise and natural scenes. Thus the visual system conserves contrast information from temporally contiguous suprathreshold images. These results require independent processing of shape and contrast information.

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◆ Spatial pooling of contrast and luminance in contrast-gain control

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The reduction of perceived contrast of a grating by the presence of a similar, surrounding grating presumably reflects lateral gain-control mechanisms. We measured perceived contrast of the centre grating while varying the surround size, contrast, and mean luminance. Stimuli were 4 cycles deg⁻¹ sinusoidal gratings (width: centre 1, surround 2–5 deg; contrast: centre 0.2, surround 0.0/0.4; mean luminance: centre 20, surround 10, 20, and 40 cd m⁻²). Subjects compared the contrast of the test stimulus centre to a comparison stimulus of variable contrast with no surround. Perceived contrast was measured by determining the point of subjective equality for test and comparison stimuli by the method of constant stimuli and 2AFC task. We found that a difference in mean luminance (with zero surround contrast) between centre and surround always reduced the perceived centre contrast, regardless of surround luminance. The effect was gradually reduced with increased surround sizes. A high-contrast surround reduced the perceived contrast of the centre grating at all centre/surround luminance combinations. Now, increasing the surround size further increased the reduction, but the reduction was greatest when centre and surround shared the same mean luminance.

The effects of different surrounds suggest spatial pooling of both the surround contrast and surround luminance in contrast perception.

◆ Contrast adaptation: dynamics of feedback control

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Detection thresholds for a brief test pulse superimposed on a flickering background have asymmetric dynamics. After a step increment of the contrast of the background flicker, test thresholds attain their steady state very rapidly (within 40 ms). However, after a step decrement of the background contrast, thresholds for the test pulse show prolonged elevations above their steady state level [Poot et al, 1999 *Investigative Ophthalmology & Visual Science* **40**(4) S46].

Here we report that a divisive feedback structure for contrast gain control can explain the observed dynamics. The background signal $I(t)$ is divided by a gain control signal $A(t)$, which yields the output $O(t)$ of the gain control loop: $O(t) = I(t)/A(t)$. The dynamics of the divisive gain control is governed by the output $O(t)$ of the control loop: $dA/dt = f(O, A)$. Many choices for the function $f(O, A)$ correctly predict asymmetric dynamics of contrast adaptation. We compare the predictions of these feedback models with our psychophysical results, and also with the results of DeWeese and Zador (1998 *Neural Computation* **10** 1190–1202) for optimal adaptation to contrast steps.

◆ Matched filtering and probability summation in flicker detection

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We have measured detection sensitivities for foveal, photopic, sinusoidal flicker at 1–20 Hz as a function of stimulus duration in dominant external temporal noise. The purpose of adding the noise is to reveal properties of the central detector (rather than retinal filtering), and, specifically, to allow calculation of detection efficiencies. The results are consistent with the following two-stage detection process. Detection of one flicker cycle is determined by a temporal matched filter applying a criterion signal-to-noise ratio to the integrated signal. Detection of a longer stimulus that consists of several cycles is aided by probability summation over what appears as independent presentations of the single cycle. The scheme resolves an apparent conflict between prediction and experimental results regarding the dependence of sensitivity on temporal frequency. Graham and Hood (1992 *Vision Research* 32 779–787) argued that detection sensitivity based on a matched filter in dominant ‘early’ (eg external) noise should be frequency-independent, whereas in fact weakly but monotonically decreasing functions are observed (Rovamo et al, 1996 *Vision Research* 36 3767–3774). According to our model, the single-cycle matched filter produces a falling square-root dependence on temporal frequency, which (for stimuli of constant duration) is mitigated by the increased opportunity for probability summation offered by the larger number of cycles contained in stimuli at higher temporal frequencies.

◆ Properties of mechanisms underlying contextual effects in fine-discrimination tasks

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We investigated how a 4 deg, 4 cycles deg⁻¹ sinusoidal grating surround affects the ability to make fine spatial discriminations in a centre grating of 40 min of arc, based on differences in contrast, spatial frequency, and orientation. Test contrast was 0.1; surround contrast varied from 0.025 to 0.5. Test and surround were in-phase or 180° out-of-phase, and either abutted or were separated by a 4 min of arc gap of mean luminance. Each condition was run in a separate block of 80 trials. Differences to be discriminated were adjusted individually for each observer to yield a d' of approximately 1.2 in no-surround control conditions and fixed for all conditions. A two-alternative signal-detection rating procedure was used to measure how performance changed with condition, and results were plotted as contrast-versus-performance functions. For in-phase, abutting gratings slight enhancement was seen in some observers at low contrast. Performance plunged when surround contrast equalled test contrast; it remained low for contrast and spatial-frequency judgments but rose again at higher surround contrasts for orientation judgments. For out-of-phase, abutting gratings performance gradually declined; at 50% contrast there were no phase differences. A gap significantly reduced or eliminated effects due to both surround contrast and phase. Possible mechanisms underlying these results are discussed.

POSTER SESSION

COLOUR

● A filter model of chromatic perceptual transparency

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Research on the colour conditions for perceptual transparency has focused on variants of the episcotister model proposed by Metelli. These additive models have been found to describe the luminance conditions for perceptual transparency in achromatic displays very accurately, but they are less successful in the chromatic domain. We propose an alternative psychophysical model that is based on filter transparency. A computer simulation revealed that this model does indeed describe colour relations that are found in situations where a surface is covered by a transparent filter more accurately than the additive model. In two psychophysical experiments we compared the predictions of the filter model directly with those of the additive model. In a four-colour stimulus, three colours were fixed in such a way that both models made unique and clearly different predictions for the remaining colour C. The subjects then searched for the colour C that optimised their impression of transparency. Our results show that the subjects' settings conform very closely to the predictions of the filter model and deviate systematically from those of the additive model. We therefore conclude that the filter model describes the colour conditions for perceptual transparency more accurately than the additive model.

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● **Perceptual scaling of the gloss of a one-dimensional series of painted black samples**

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Gloss is an attribute of visual appearance that originates from the geometrical distribution of light reflected by surfaces [Hunter, 1987 *The Measurement of Appearance* 2nd edition (Chichester/New York: John Wiley)]. Practically, specular gloss (ISO 2813) is used to grade the appearance of gloss, but the relation between the visual percept and specular gloss is unknown. Here, we investigate the perceptual spacing of a one-dimensional gloss scale. A series of flat painted black samples was manufactured, corresponding to ten specular gloss values. The experiment was conducted in a light booth in which the observation and illumination geometries were controlled (ASTM D4449-90). Difference scaling was used to evaluate perceptual differences. The task of the observer was to choose, between two pairs of samples, the pair that exhibited the largest visual difference. The visual scale was constructed from the judgments between the pairs by using a maximum-likelihood technique (Maloney and Yang, 1997 *Perception* **26** Supplement, 128). For all observers, the results showed a similar nonlinear relation between the gloss percept and the gloss index. These results could be interpreted as the conjunction between two percepts, the contrast gloss and the distinctness of image. Profiles obtained at $60^\circ/60^\circ$ and at $20^\circ/20^\circ$ incidence/reflection configurations were found to be alike. This result suggests the possibility of a perceptual gloss constancy mechanism.

[Supported by BNM.]

● **Perceptual colour transparency determined by the contrast ratio in colour-opponent channels**

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Psychophysical experiments were performed to investigate the conditions of colour change leading to perceptual colour transparency. Observers viewed a display simulating a transparent surface on the classical bicolour ground. Colours in areas overlapped by a filter were set by the experimenter with the use of a general convergence model (GCM). The convergence model (CM) proposed by D'Zmura et al (1997 *Perception* **26** 471–492) has one scalar parameter, α , representing degree of contrast change, while α in the GCM is described as a vector to represent contrast change independently along each of the three axes in colour space. The displayed colours were set by varying these parameters and observers were asked whether or not a transparent surface was perceived. Experimental results showed that the perception of transparency occurred for broader range of parameters than predicted by the CM and agreed well with the GCM in which the colour contrast was calculated in colour-opponent channels independently. Moreover, contrast change in each axis in DKL colour space (Derrington, Krauskopf, Lennie, 1984 *Journal of Physiology* **357** 241–265) contributes differently to perceptual transparency—the achromatic contrast was judged more rigidly than the chromatic. Monte-Carlo simulation with a set of Munsell colour chips and plastic filters suggests that these experimental results can be explained by a computational interpretation of the GCM as an approximate model both for additive and for subtractive colour mixtures.

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● **Relational colour constancy across different depth planes**

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Relational colour constancy refers to the constancy of perceived colour relations in a scene under changes in illuminant. It is known that discriminations involving relational colour constancy can be made across the two eyes (Nascimento and Foster, 2001 *Vision Research* **41** 2601–2606). Can they also be made across different depth planes within the same scene? To address this question, observers were presented with simulations on a computer-controlled monitor of Mondrian-like coloured patterns comprising 49 (7×7) abutting $0.9^\circ \times 0.9^\circ$ square Munsell papers under two successive daylights with correlated colour temperatures of 25 000 K and 6700 K. The spectral reflectance of the central paper under the second daylight varied randomly from trial to trial in

such a way that any colour change was in the direction of the daylight locus. Observers viewed the stimuli binocularly at 100 cm. In different experimental sessions, the part of the screen showing just the central paper was displaced optically towards the observer by 0, 35, and 70 mm, corresponding to disparities of 0, 7, and 16 min of arc, respectively. Observers' ability to detect changes in spectral reflectance was almost exactly the same in the three conditions, suggesting that surface-colour judgments can be made across different depth planes within the same scene. [Supported by BBSRC and EPSRC.]

● **How many basis functions are needed to reproduce coloured patterns under illuminant changes?**

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Some approaches to surface-colour perception assume that spectral reflectances may be mathematically well represented by low-dimensional linear models. In practice, however, principal component analyses of natural scenes illuminated by daylight suggest that observers need about six basis functions to represent adequately surface reflectance spectra [Nascimento et al, 2001 *Investigative Ophthalmology & Visual Science* **42**(4) 3871]. This requirement might be relaxed if representations were required only to appear invariant under illuminant changes. To test this hypothesis, observers were presented with computer simulations of pairs of Mondrian-like coloured patterns comprising 49 (7×7) abutting $1 \text{ deg} \times 1 \text{ deg}$ square Munsell papers; in half of the trials, the spectral reflectances of the surfaces were replaced by an approximation comprising a variable number of basis functions; observers had to report whether the two patterns were of the same materials. In one condition the patterns appeared under identical daylights of correlated colour temperature 6700 K and in another condition under two different daylights with correlated colour temperatures of 25 000 K and 6700 K. Under both identical and different illuminants, most observers required at least five basis functions for the discrimination of the patterns to be at chance, suggesting that low-dimensional linear models provide insufficient colour representation in this context.

[Supported by EPSRC.]

● **Blue and yellow colour channels have different spatial-frequency characteristics**

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There is a growing body of evidence that the yellow–blue (YB) colour opponent mechanism is split into two unipolar (non-opponent) mechanisms (eg Sankeralli and Mullen, 2001 *Visual Neuroscience* **18** 127–135). We have also found evidence for two unipolar subchannels from studying a colour illusion called high-spatial-frequency tritanopia (Logvinenko, 2001 *Perception* **30** 223–232). Particularly, essential differences in the spectral characteristics of the yellow and blue subchannels have been found; they are not mirror images of each other as often suggested. Now, we are reporting that the subchannels have rather different spatial-frequency characteristics too. Specifically we found that only the blue illusory colour can be observed at a medium spatial frequency ($4 \text{ cycles deg}^{-1}$). However, when the spatial frequency is as high as $8 \text{ cycles deg}^{-1}$, both yellow and blue are produced. This suggests that the appearance of blue and yellow results from mechanisms with different spatial-frequency characteristics. More specifically, it implies that the yellow subchannel has better spatial resolution.

● **Ultraviolet colour vision in birds: inferring physiology and perception from behaviour**

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A broad understanding of vision can be reached by a comparative approach. Both humans and birds have cones sensitive to long, medium, and short wavelengths. In addition, most birds have a fourth cone, which is either a violet-sensitive cone that has some sensitivity to ultraviolet (many non-passerines) or a cone that has maximum sensitivity to ultraviolet (oscine passerines). It is unclear whether the output of the violet/ultraviolet cones contributes to chromatic or achromatic visual mechanisms in birds. To investigate, we have developed an ultraviolet 'colour blindness' test, which we have given to species representative of both non-passerines (Japanese quail) and passerines (European starlings). Both species of bird learned to discriminate between orange versus red (a long-wavelength positive control), and ultraviolet versus 'not ultraviolet' stimuli.

As the stimuli were designed to be impossible to differentiate by achromatic mechanisms, we conclude that the output of the violet/ultraviolet cone is used in a chromatic colour-vision system.

[We thank Innes Cuthill, Arthur Goldsmith, and Danny Osorio for useful discussion.]

● **Neurons in marmoset V1 encode spatial cone-contrast**

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To assess the neural mechanisms underlying colour contrast and constancy, we probed the colour selectivity of marmoset V1 neurons using cone-isolating stimuli tailored to the cone spaces of individual trichromats and dichromats.

Neurons were tested with patches of cone-isolating (S or L/M1/M2) and cone-combination ($L \pm M1/M2$) stimuli. Each stimulus set had a fixed coloured background (eg neutral, yellow, or orange for the S-isolating sets) with a range of spatial cone-contrasts (stimulus/background). The relative proportions of colour-selective versus luminance-selective cells were similar in dichromats and trichromats (15%–25%), as were proportions of S-cone-selective cells. The responses of colour-selective cells increased with increasing cone-contrast of the preferred type, but with different gains for different coloured backgrounds. For example, for a given S-cone-contrast, S-selective responses for the neutral background were higher than those for the yellow or orange ($-S$) backgrounds. This result is surprising since the $-S$ backgrounds would be expected to elicit maximal sensitivity from the S cones. Against an $-S$ background, though, the range of $+S$ contrasts encountered will expand, so the gain of contrast-selective cells may be reduced to avoid saturation. Thus, colour-selective cells in V1 of both dichromatic and trichromatic marmosets encode cone contrasts, consistent with mechanisms underlying colour constancy.

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● **Colour-independent shape selectivity in inferior temporal cortex**

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Primates recognise objects largely independently of defining features of the retinal image. These invariances of object recognition are thought to be served neurally by the inferotemporal cortex (IT) of the macaque brain, whose neuronal response properties are largely invariant to the physical changes of the image. Humans (and monkeys) are also able to identify a shape when it is presented as a chromatic or as an achromatic image. The effect of colour on the IT, however, is treated controversially in the literature. In our experiments we tested whether the removal of chromatic information from the images of complex shapes affects the discrimination performance of the macaque and the response properties of IT cells. We recorded 34 neurons from two monkeys performing either a fixation or a shape-discrimination task. There was no difference in the neuronal properties of the fixating and of the discriminating animals. Our results did not show a significant difference of the firing rates and of the shape selectivity of the neurons in the chromatic and achromatic conditions. Discrimination performance was similar for the achromatic and coloured images. Our results suggest that there are cells in the IT which play a role in the colour-independent recognition of shapes.

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● **Linear colour segmentation and its implementation**

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Human vision has an ability to discriminate coloured objects and recognise their colours invariant to substantial variations of the geometry of object, illumination, and viewing. Is it possible to provide computer vision systems with a similar capability? We have developed a group of algorithms employing a physical approach to colour image processing that performs colour image segmentation and surface colour estimation. The segmentation algorithm subdivides a multispectral image at material boundaries (ie discontinuities of reflectance properties), thus ignoring shading and shadows. The colour constancy algorithm provides estimation of reflectance properties for each segment. Algorithms are based on the generalised linear theory of spectral stimulus formation. This theory shows that, in a wide variety of viewed scenes, uniformly coloured objects are projected to the colour space of the sensor as planar, linear, or point-like clusters.

A framework method for colour image segmentation combines the RGB histograms using clustering and region merging techniques. The clustering algorithm consists of two steps. It starts by partitioning the 3-D colour histograms of an image into unimodal clusters by a hierarchical watershed method. As the algorithm progresses, clusters are split to fit the point/line/plane model. To analyse cluster shapes in the colour space, the generalised Hough transform method, the shooting method, and the eigenvector method have been used and compared. At the last stage of processing, a region-merging technique is used to remove erroneous boundaries. Testing this algorithm with both artificially generated and real images showed quite reliable results. It is possible that the brain implements similar algorithms.
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● **Indirect evidence for von Bezold–Brücke hue shifts for small differences in luminance**

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The von Bezold–Brücke hue shift is always connected to relatively large differences in the intensity of spectral stimuli. An experiment is reported in which a very sensitive procedure (MUEST) was used to measure the offset and the steepness of the psychometric function for the detection of motion direction (the Anstis–Cavanagh method of equal-brightness determination). The Anstis–Cavanagh method consists of four sequentially presented frames. Two of them—the test frames—consist of the colours for which the luminance contrast has to be determined. The other two frames—the comparison frames—consist of two colours with a fixed luminance contrast. For several stimulus positions in the colour triangle (as close as possible to the spectral locus) we measured the described psychometric function for the detection of motion direction as a function of luminance differences. We found that the width of the psychometric function varied systematically for different colours, with the steepest functions at those colours where low von Bezold–Brücke hue shifts are expected. These differences in steepness can be attributed to interaction of colour and luminance differences. These hue differences are ascribed to the von Bezold–Brücke effect. Two levels of contrast in the comparison stimuli were used to test this hypothesis.

● **The S and L–M chromatic systems have matched temporal processing characteristics only at low-light levels**

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McKeefry et al (2001 *Vision Research* **41** 245–255) found that the S and L–M chromatic systems are matched in sensitivity for temporal modulation, whereas earlier studies claimed that the L–M system has a faster response than the S system. McKeefry et al took great care to eliminate luminance artifacts; it is therefore possible that previous measurements of chromatic sensitivity are contaminated at high frequencies by L–M signals entering the magnocellular pathway. However, it is also possible that differences between the S and L–M temporal response are light-level dependent. We measured temporal sensitivity functions for S and L–M lights at three different light levels (6, 20, and 60 cd m⁻²) on a CRT monitor. The test light was an annulus with a 3 deg outer diameter divided into four segments. To control for luminance artifacts, one of the segments contained a temporally modulated chromatic signal embedded in a field of broadband noise; the other three segments contained noise only. We confirm the McKeefry et al finding that the S and L–M chromatic systems have matched temporal responses at 6 cd m⁻² (approximately the same luminance as was used in their study). At higher light levels, however, the L–M system is faster than the S system in some conditions.
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● **Resolution acuity in peripheral vision for achromatic and S-cone isolating gratings in early glaucoma**

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Peripheral resolution acuity for achromatic gratings is limited by the density of the underlying ganglion cells (sampling limited). Recent studies have shown that peripheral grating resolution acuity for short-wavelength cone (S-cone) isolating gratings is also sampling limited and largely

unaffected by lens absorption or optical defocus. Thus it permits us to make direct estimates of localised S-cone-driven ganglion cell density. The aim of this study was to determine if there is any selective reduction in S-cone-driven relative to achromatic ganglion cell density in early glaucoma. Resolution acuity was measured at 13 deg eccentricity in four oblique meridians in eighteen eyes with early glaucoma. The results were compared to a group of seventeen age-matched normal eyes. Mean achromatic acuity was significantly lower in the glaucoma patients compared to normals (2.40 versus 4.01 cycles deg⁻¹). Mean chromatic resolution was also significantly lower in the glaucoma patients than normals (0.66 versus 0.99 cycle deg⁻¹). The chromatic/achromatic resolution ratio was not significantly different in those with glaucoma compared to the normals. These results indicate that there is no selective reduction in S-cone-driven ganglion cell density in early glaucoma.

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● **The effect of number of cycles on detection of S-cone isolating gratings in central and peripheral vision**

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The contrast sensitivity for detecting a luminance grating improves with an increase in the number of cycles. This improvement has been attributed to a summation mechanism integrating the responses of independent contrast detectors. We wanted to determine if the effect of the number of cycles is the same for S-cone isolating gratings as for luminance gratings. We measured contrast sensitivity thresholds for such gratings in the fovea and at 20 deg in the temporal retina. The number of cycles necessary to obtain more gradual increase of contrast sensitivity was greater at a higher spatial frequency and at larger eccentricity. Although the dependence of contrast sensitivity on number of cycles was of the same form for S-cone and luminance gratings, the sensitivity of S-cone gratings increased over a larger area than the sensitivity of luminance or red–green (Mullen, 1991 *Vision Research* **31** 119–130) equiluminous gratings.

● **Temporal summation of S-cone signals: dependence on signal polarity and retinal eccentricity**

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We reported previously that temporal integration of S-cone selective luminance signals depends on signal polarity. Bloch's law was found to be valid over a longer time interval for decrements than for increments (Zlatkova and Vassilev, 1999 *Perception* **28** Supplement, 65). The stimuli were presented at a fixed eccentricity of 12.5 deg. We later found that spatial summation of such signals depends on retinal eccentricity (Vassilev et al, 2001 *Perception* **30** Supplement, 17–18). This also made it necessary to study temporal summation as a function of eccentricity in order to search for any correlation between the temporal and spatial properties of the mechanisms processing S-cone ON and OFF signals. In the present experiments, the background was a mixture of 3 cd m⁻² blue light and 300 cd m⁻² yellow light. The test stimuli were blue-light increments or decrements at different retinal locations. Stimulus area was larger than Ricco's area and it was also scaled to be inversely proportional to the S-cone density. Contrary to the findings in the periphery, no difference in the temporal summation of S-cone ON and OFF stimuli was found within the central 0–10 deg of the retina.

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● **The effect of apparent motion (ie the ϕ motion effect) of coloured stimuli on reaction times in a simple discrimination task**

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Our aim was to find out if it is possible to capture attention by using a colour version of the ϕ motion effect and, following on from earlier experiments, if the use of equiluminous and black backgrounds suggests that colour edges have a role to play in this attentional capture. Participants were presented with a version of the ϕ motion effect, which used colour dots. According to the effect, participants should perceive apparent motion of the initial coloured dot to a second dot that shares the same colour rather than another dot that does not. Results suggest that the apparent motion effect can occur with colour, and in turn that this can successfully cue attention. There was no evidence of participants reacting faster against a black background, suggesting that they may have relied largely or even entirely on surface colour in this task.

● **Kinetic colours: motion contrast does not reduce chromatic contrast**

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A coloured background induces a contrasting colour in a figure set against it. Previous studies have shown that segmentation cues, such as differences in disparity or texture, may reduce such simultaneous-contrast effects. Here we used two variants of a nulling technique to investigate whether segmentation from motion can also inhibit contrast induction. In the first condition, a stationary $1\text{ deg} \times 1\text{ deg}$ square was set against a textured background ($20\text{ deg} \times 30\text{ deg}$) that was continuously translated, rotated, or warped, whilst simultaneously alternating in colour between red and green along the L–M axis. In the second paradigm, the square moved sinusoidally against a chromatic gradient on a stationary background. In both conditions, the chromaticity of the target square was modulated along the same chromatic axis as the background, and we measured the strength of the induced contrast by asking the observer to adjust the amplitude of this modulation until the perceived colour of the square remained constant. Observer settings for the motion conditions were not significantly different from those for motion-free controls. We found no evidence that segmentation from motion can disrupt simultaneous-contrast induction. [KW is supported by a Barbour scholarship.]

● **Colour coding mechanisms mediating visual search**

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We explored colour coding mechanisms mediating colour discrimination in a visual search task. On the equiluminance plane in Derrington–Krauskopf–Lennie opponent colour space, we measured the discrimination threshold (corresponding to response rate of 75% in discriminating target colour from distractor) when distractors were (a) at the adaptation point, (b) on the LM axis, (c) on the S axis, or (d) on an intermediate-hue axis. The target colour was changed in eight directions from the distractor on the equiluminance plane. In conditions (b) and (c), the colour discrimination thresholds selectively increased along LM and S axes, respectively, from those in condition (a), whereas in condition (d) thresholds also increased along the intermediate-hue axis. Analyses based on the probability-summation model showed that the colour discrimination thresholds are determined by multiple colour mechanisms tuned to colour opponent axes and to intermediate-hue axes. Furthermore, it is suggested that the sensitivity of the multiple colour mechanisms varies depending on top–down information, such as advance knowledge of target colour, etc.

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● **RTs in colour space; effects of equiluminance and adaptation**

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Simple response times (RTs) were recorded to the ramped onset of equiluminous, radially symmetric Gaussian spots ($SD = 0.2\text{ deg}$). Eight main chromatic axes were tested, their hues being specified in equiluminant colour space incorporating red–green and blue–yellow cone-opponent axes. RT versus $1/\text{RMS}$ cone contrast functions were linear. The longest RTs were obtained with the blue (90°) stimulus and the shortest with the red (0°) and green (180°). Intermediate RTs were obtained for the yellow (270°) stimulus. These results were obtained whether stimuli were presented at equal cone contrast or equal suprathreshold contrast. They were, however, critically dependent on individual equiluminance settings. Local adaptation effects were measured by plotting RT as a function of foreperiod. This showed minimal interaction between the red–green and the blue–yellow stimuli.

● **Perceptual influences on the development of basic colour categories in young children**

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Substantial evidence suggests that colour sensations are categorised into a set of discrete perceptual categories that are universal across culture and language [eg Berlin and Kay, 1969 *Basic Color Terms* (Berkeley, CA: University of California Press)]. However, recent cross-cultural

studies have demonstrated linguistic influences on colour categorisation, suggesting that colour categorisation is linguistically relative and culturally defined (eg Davidoff et al, 1999 *Nature* **398** 203–204). We tested these contrasting hypotheses in a developmental study that investigated whether perceptual colour categories develop prior to colour terms. We compared the performance of a group ($N = 17$) of children (aged 2–3 years) on a perceptual task of colour discrimination to a conceptual task of colour comprehension. In each task, the perceptual relationship between the target and distractor colours was manipulated systematically over two conditions (distant versus adjacent distractors).

We found that: (i) children could discriminate basic colour categories accurately before they could reliably comprehend basic colour terms; (ii) this was especially marked for brown and grey that appear later in development; (iii) perceptual similarity selectively influenced colour comprehension, as target colours were comprehended significantly better when presented with distant, rather than adjacent, distractors. Our results are consistent with the ‘universalist’ perspective and suggest that perception influences the developmental acquisition of basic colour terms.

● **Gender differences in colour-naming task**

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In an unrestrained-choice colour-naming task, forty female and forty male first-year university students responded to 25 coloured chips of the Munsell series. The colour names were classified in three main types of colour words (basic landmark: yellow, blue, red, green; other basics: pink, purple, brown, orange; and non-basics). For each category, colour names given by participants were either a single or a qualified word. Qualifiers were then classified in three categories corresponding to the three subjective attributes of colours: hue, saturation, and brightness.

Both men and women relied more on basic and other-basic colour terms but no significant difference between gender was found. Men use significantly more simple words than women; this difference is particularly prominent for samples including a red component. Among the qualifiers, brightness attribute is equally used by both sexes, but women use significantly more qualifiers related to hue to name samples including a red component.

This result is consistent with previous findings on sex-related differences in colour vocabulary (Nowaczyk, 1982 *Language and Speech* **25** 257–265), but identify the origin of the differences in the broader use that women do of hue and saturation qualifiers rather than in the type of words.

● **The categorisation of colours measured with the Stroop effect**

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Numerous studies have shown that humans classify colours into a restricted number of categories. These results are, however, often dependent on the choice of colour terms made available to the subjects. Moreover, most categorisation studies use monochromatic stimuli, yielding results difficult to compare with those of the electrophysiological literature. We therefore designed a new technique to measure the boundaries of colour categories, and used it to investigate the classification of colours in a physiologically relevant (MacLeod–Boynton) colour space. During training, our subjects ($N = 17$) learned to associate a colour name with each of four white shapes (square, disc, rectangle, or diamond) presented on a dark background. Upon presentation of one of the four shapes, the subjects had to name it as quickly as possible with its associated colour name. We measured the subjects' verbal reaction time for the correct naming of the four shapes. For the data collection proper, the task remained the same, except that the shapes were presented not only in white (the control condition), but also in various colours (all of equal luminance). When the colour of the stimulus was congruent with its associated colour name, the reaction times were shorter than for the control. The reaction times grew proportionally with the difference between the stimulus physical colour and its associated colour name, similar to the well-known Stroop effect. The curves relating the subjects' reaction times to the colour of the stimulus yield estimates of the boundary for each colour category tested. These results are compared with those obtained with standard colour categorisation paradigms, as well as with the colour tuning of single neurons in the visual pathways.

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● **The effect of Stroop interference on the categorical perception of colour**

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We performed three experiments to investigate the effect of Stroop interference on the categorical perception (CP) of colour. Colour discrimination tasks reliably produce a CP effect—discrimination

for stimuli that straddle a category boundary is significantly better than for stimuli that fall inside the same category. However, Roberson and Davidoff (2000 *Memory & Cognition* **28** 977–986) found a verbal-interference task to have a diminishing effect on CP and hence suggested CP may not be a truly perceptual phenomenon but rather a direct effect of language. A recent study (Pilling et al, 2002, submitted for publication) showed that CP can survive verbal interference. The strength of CP was here further investigated by introducing a different kind of verbal interference—Stroop interference. In experiments 1 and 2 either a congruent or an incongruent colour word was presented with the memory stimulus. Congruent colour words were found to have a strongly facilitating effect on CP whereas the presence of incongruent colour words eliminated CP. Experiment 3 introduced the Stroop interference at the response stage (the test stimuli were presented with either congruent or incongruent colour words), and results again suggest that giving the correct verbal code facilitates colour discrimination.

PERCEPTUAL ORGANISATION

● **Imaging contextual modulation in area V1**

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We used event-based fMRI to study the contribution of area V1 to contextual salience. Six subjects viewed Gabor elements arranged in two ellipses (main axis diameter 4 deg) to the left and to the right of fixation. Observers were cued to report ellipse shape (main axis orientation) on either the left, the right, or both sides of fixation. The orientation of Gabor elements assumed one of three configurations: tangential, normal, or random to the ellipse, creating a closed contour, a radial pattern, or a random pattern, respectively. Both the reported side(s) and the Gabor configuration were randomly interleaved and trials were well separated in time (16 s). Gabor configuration altered the BOLD response significantly in area V1, and possibly other retinotopic areas, but apparently not in non-retinotopic areas such as area LO. This would appear to contrast with previous studies of visual segmentation, which produced little evidence for functional specialisation among visual cortical areas (eg Mendola et al, 1999 *Journal of Neuroscience* **19** 8560–8572). Our results are consistent with the notion that area V1 and its intrinsic connectivity make a specific and unique contribution to contextual salience. In addition, results obtained with various alternative stimulus configurations tell a cautionary tale about the interpretation of MRI data.

● **Grouping of patches with alternating contrast polarities in Gabor and Gauss lattices**

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Grouping phenomena are usually investigated with Gabor patches in a flanked target-detection paradigm or a 'snake'-detection paradigm. We focus on grouping as reported by observers after brief presentations of patches in geometric lattice configurations. Grouping is not influenced by polarity alternations between elements in the snake-detection paradigm (Field et al, 2000 *Spatial Vision* **13** 51–66). The current research was motivated by the question whether this result would generalise to the Gabor lattice paradigm. We manipulated relative distances between elements in six levels. We crossed this proximity manipulation with four conditions of polarity alternation: (i) alternation in the alignment orientation; (ii) alternation in the orthogonal orientation; (iii) double alternation; and (iv) no alternation. For comparison, we included matching stimuli without the sinusoidal convolution in the Gabor function, ie consisting of patches with a luminance profile that reflects a Gaussian. Results showed a definite influence of polarity alternations in Gauss blob lattices, while these did not yield any effect in Gabor lattices. A slight effect was found only for the lattices with the smallest distance between aligned patches, for which grouping by continuity (alignment) and proximity are cooperative. Thus, our data are consistent with findings from the snake-detection paradigm.

● **Mechanisms of purely temporal figure–ground segregation**

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We investigated the mechanisms underlying figure–ground segregation based on purely temporal cues. The standard display consisted of 400 luminance-defined colons that flipped (ie rotated instantaneously by 90°) synchronously within both figure and ground, and asynchronously between them. In a 4-AFC task, subjects located the figure correctly (i) up to a flip frequency of

23 Hz, corresponding to a threshold delay of 22 ms between figure and ground; (ii) binocularly masking the stimuli did not impair performance; (iii) replacing the colons by Mexican hats; or (iv) presenting green colons on an isoluminant red background increased thresholds to 45 ms and 65 ms, respectively; (v) when the stimuli were displayed dichoptically, subjects still perceived the local motion but were unable to segregate figure from ground. We assume that, in each experiment, a motion mechanism detects the flipping and passes its output to the next higher (motion) detector which computes the segregation, the latter being second-order in experiments (i) and (ii), and third-order in experiments (iii) and (iv). Whereas experiment (v) is consistent with the assumed lack of a fourth-order motion detector, the ability to perceive the segregation in experiment (iv) contradicts a recent model by Lu and Sperling (1999 *Proceedings of the National Academy of Sciences of the USA* **96** 8289–8294).

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● **Spatiotemporal interpolation and perception of illusory contours**

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Temporal span for the visual system to integrate inducing figures across space and time was examined. Irregular illusory contour figures were used as materials. Inducing figures were presented one by one successively, and a small dot was presented around the perceived illusory contour. We manipulated total duration of inducing figures. Observers were required to decide whether the dot was located inside or outside the illusory figure. Perceived positions of illusory contours were estimated by the psychophysical, double-staircase method. Estimated positions of illusory contours in successive presentation conditions were compared with those in a fully visible condition. Results showed that perceiving an illusory contour was more difficult when inducing figures were temporally separated. But results also suggest that, under certain temporal conditions, edge may be interpolated. Temporal window hypothesis on edge integration across both space and time is discussed.

● **Subthreshold summation does not occur with illusory contours**

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Superimposing a target on the illusory contour of a Kanizsa square figure reportedly facilitates detection. This has been explained in terms of subthreshold summation (Dresp and Bonnet, 1995 *Vision Research* **35** 1071–1078). However, Pardieu et al (2001 *Perception* **30** Supplement, 37) found no evidence of subthreshold summation in the Ehrenstein illusion and suggest that reduction of spatial uncertainty facilitates detection. In the present study we re-examined these alternatives for the Kanizsa square. The detection threshold (70%) for a target line was measured for ten participants. A 4AFC staircase procedure was used. The target was either superimposed on the illusory contour of a Kanizsa figure, located between pairs of small dots (no illusory contour: three variations), or presented alone. There was a significant main effect of stimulus condition ($F_{4,36} = 4.952$, $p = 0.003$). Detection thresholds in the Kanizsa condition were significantly worse than dot conditions in which the dots were placed at the end of the target ($F_{1,9} = 6.623$, $p = 0.030$; $F_{1,9} = 11.777$, $p = 0.007$), but no different when the dots were distant or the target was presented alone. Clearly, subthreshold summation is not supported by these results. This is congruent with previous research on the Ehrenstein figure and confirms that subthreshold summation does not occur with illusory contours. The results suggest that reduced spatial uncertainty facilitates detection.

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● **Completion time of visual occlusion: effect of contour orientation**

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We investigated the temporal dimension of amodal completion in visual occlusion. We hypothesised that completion time depends on contour orientation, so that normally (vertically–horizontally) oriented contours will be completed faster than oblique ones. The prime-matching paradigm was used. Prime and target stimuli were both presented in normal and oblique (45°) orientations. The primes were pairs of identical figures: CC (truncated squares: good continuation maximised), SS (hexagons: symmetry maximised), and AA (ambiguous patterns: circle occluding either C or S). Temporal distribution of stimuli was as follows: prime 400 ms, ISIs 20 ms, and targets until response. Targets were the 'same' pairs, CC and SS, and the 'different' pairs, SC and CS.

Each 'same' target had its positive prime (CC or SS) and its ambiguous prime (AA). Subjects were asked to answer whether figures in the target stimuli were same or different. The 'same' RTs were analysed. The effect of ambiguous prime was systematically weaker (longer RT) than the effect of positive primes. A significant interaction form by orientation was obtained: the effect of ambiguous prime was closer to the effect of positive prime when the contour was normally oriented irrespectively of form (C or S).

- **What we can learn from the shape of holes**

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We used holes to investigate the perception of shape. The area within a hole is a background region and therefore shapeless (because contours belong to figures), yet people recognise the shape of holes as well as the shape of objects [Palmer, 1999 *Vision Science* (Cambridge, MA: MIT Press)]. If what people perceive is the surrounding figure, then its shape has a reversed convexity/concavity structure compared to the hole region perceived as figure. Using a reaction-time task we exploited the fact that observers are faster at judging the position of convex vertices (Bertamini, 2001 *Perception* 30 1295–1310). We predicted and found that a manipulation of figure/ground organisation (experiments 1–3) produces a crossover interaction (ie a reversal of the relative speeds when the same regions were perceived as holes instead of objects). With stereoscopic information, so that depth stratification was unambiguous, the interaction was even clearer (experiments 4–6). We conclude that the enclosing object is perceived as having shape, and that a change from figure to hole always reverses the encoding of curvature polarity. In turn, polarity obligatorily affects the processing of position. Results also show that a polarity reversal for a region can be achieved without altering closure or number of objects.

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- **Image regularity versus 'object' regularity: effects of symmetry and repetition in folded bands**

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Regularities in images of folded bands were judged by ten naïve observers. The 2-D image of these folded bands could comprise a repetition or a bilateral symmetry of their V-shaped endings. The unfolded bands themselves could also comprise a repetition or a symmetry. In the experiment, the participants were asked to judge the type of regularity (repetition or symmetry) in either the image (ie the folded band) or the object (ie the mentally unfolded band), following different cues before the actual presentation of the band. From the results it can be concluded that performances on the image level were equal for both types of regularities, whereas performances on the object level depended strongly on the image regularities. More specifically, image symmetries appeared to be much more difficult to overcome than image repetitions when judging the object regularity.

- **Spatial grouping in symmetry detection**

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Experimental data and results of network simulation in a project on symmetry detection in small (3 cm × 3 cm) binary patterns are presented. Eleven patterns in a group of twenty were symmetrical about the vertical, horizontal, and positive or negative oblique axis. The patterns were presented on a computer screen for 5 s and 10 s in different experimental sessions. The observers' task was to draw the patterns immediately after observation. The recognition was more sensitive to formal organisation. Patterns with a symmetry axis were better remembered than those with a centre of symmetry. The most efficient axis of symmetry was the vertical one, followed by horizontal and oblique axes. Following this part, an ART I-type net was trained with the original patterns by adjusting their learning parameters. Then the patterns reproduced by the observers were presented to the group for identification. When comparing the performance of the group which showed no preference for any symmetry, the error recorded was similar to that obtained with the observers. These results were analysed by means of perceptive theories, which suggest that the greater ease in recognising symmetrical patterns was due to previous experiences in the observers' daily lives.

● **Sex differences in the detection of global and local visual regularities**

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We investigated sex differences in the perception of global and local regularities. Stimuli were composed of oriented lines that exhibited both a global regularity in their positioning and local regularity in the pairwise correspondences of line orientations. The regularities could be symmetry or repetition. Global and local regularities could be either consistent or conflicting. The task was to detect either the global or the local regularity, depending on the instruction (“global” or “local”) before each trial. For repetition, both sexes were better (faster and more accurate) at detecting local repetitions as compared to global repetitions. For symmetry, females performed better at detecting local as compared to global symmetries, and males performed better for global as compared to local symmetries. The results for symmetry detection are consistent with the results of research into sex differences in spatial cognition conducted by Dabs et al (1998 *Evolution and Human Behavior* **19** 89–98). They showed that in wayfinding tasks males tend to use more global ‘bird’s-eye-view-perspective’ strategies and females more local landmark-oriented strategies.

● **A comparative analysis of global and local processing of hierarchical visual stimuli in young children and monkeys (*cebus apella*)**

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Pre-school children and capuchin monkeys were tested in three experiments based on a simultaneous matching to sample (MTS) where the global configuration or the identity of the local elements of hierarchical stimuli provided the relevant cues for correct choices. No time limits were imposed on the visual inspection of the stimuli. The similarity between sample and comparison stimuli was manipulated in the first two experiments. The third experiment featured the manipulation of the density of the local elements. Both children and monkeys performed at a high level of accuracy. However, monkeys, in contrast with children, showed a marked advantage in matching the stimuli on the basis of their local features. Moreover, monkeys’ accuracy in the processing of the global shape of the stimuli was negatively affected by the spatial separation of the local elements, whereas children’s matching performance was robust across testing conditions. An analysis of children’s response latencies revealed the emergence of a global precedence in the processing of the hierarchical stimuli following manipulations of the density of the local elements. Overall, these results show that differences in the processing of hierarchical stimuli by humans and monkeys emerge relatively early in childhood in tasks featuring an unrestricted exposure to the testing stimuli.

● **The role of feature-dependent backward masking in perceptual asynchrony**

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Reducing the visibility of a target object by presenting another object (mask) afterwards is called ‘backward masking’. Whether masking acts holistically or corresponding features mask one another is not clearly understood. The issue of perceptual asynchrony has been frequently investigated by sequentially changing the features of some visual stimulus and asking the subjects to decide about those changes. Feature-dependent backward masking and its possible asymmetric interactions could have affected those experiments. In this study, 8 white letters were briefly flashed in a clock-face configuration around fixation point and a colour (red or green) or orientation (horizontal or vertical grating) mask later appeared in one of the eight locations and subjects decided whether the masked letter was an ‘S’ or not. Error rates for various stimulus onset asynchronies (SOAs) were determined for colour and orientation masks differentially. We showed that high-level backward masking by orientation is strongest in SOAs around 80 to 100 ms and declines rapidly in higher SOAs; however, masking by colour is more persistent ($p < 0.05$), extending to SOAs as long as 160 ms. We conclude that colour and orientation impose asymmetric masking trends and this asymmetry could have acted as a source of uncontrolled bias in the experiments on perceptual asynchrony.

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● **The launch effect: is the radius of action a function of the time?**

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In the launch effect studied by Michotte [1963 *The Perception of Causality* (London: Methuen)] the radius of action is a critical aspect in the perception of causality: after the contact, the second moving object, from a certain distance on, seems to move autonomously. According to Yela (1952 *Quarterly Journal of Experimental Psychology* **4** 139–154) the radius of action is a function of the time. In the present research, we tested this hypothesis. The experimental paradigm of Michotte (1963) was used. In the experiment, the velocity of the second moving object (50, 75, 100 mm s⁻¹) was varied. Two values (0 ms, 30 ms) of the time interval between the moment of contact of the first object and the moment when the latter begins to move were adopted. Observers indicated where the second moving object lost its passivity and started to move autonomously. The results show that the time duration of the radius of action increases with the velocity of the second moving object, whereas the time interval after the contact is not a significant factor. Our findings suggest that the radius of action is a function of the kinetic properties of the event.

ATTENTION

● **Attention reduces the impact of prior spatiotemporal information on perceptual judgments**

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Recent theories have argued that, if the visual system has prior spatiotemporal information ('reason to believe') that a stimulus with a particular orientation will be presented, perception will be biased by these predictions. We tested this hypothesis by moving a bar in discrete steps centripetally across a CRT screen. When closest to the centre, the orientation could match the predictor orientation (previous bars) or be tilted up to 7° away (1° steps). Simultaneously with the target bar, a reference bar was presented (angular tilt between target and reference: -4° to 4°, 1° steps). Subjects reported whether target bars were rotated counterclockwise, not at all, or clockwise relative to the reference. Perception of the target was significantly biased towards the orientation of the predictors ($n = 5$, $p < 0.001$). Selective attention may modulate the balance between prior (feedback) and afferent (feedforward) information processing, decreasing the impact of the priors. To test this, subjects performed a dual task: a central colour counting task, and the orientation judgment. Withdrawing attention from the orientation task significantly increased the influence of the predictor bar on perceptual judgments ($n = 5$, $p < 0.001$). These findings support the hypothesis that selective attention modulates the balance between prior and afferent information processing.

● **Degradation of object bias in angled objects**

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Object bias for responding to targets within a single object compared to targets in different objects has been previously reported as proof of object-based attention. Many of these studies, however, confound linearity with the concept of an object, and new evidence has emerged to suggest that discontinuities in linearity provide the boundaries for parsing visual stimuli. To investigate the role of linearity in object bias, several experiments were conducted to assess the strength of the effect in linear and angled objects. Data from a number of experiments are presented that show that in simple object-based target-discrimination tasks, the presence of an angle in an object disrupts the same-object benefit. Object benefit is only apparent for objects that provide a straight contour or line between two targets. The results are discussed in terms of the reorientation of attention and line tracing.

● **Hemisphere and the gap effect for hand movements**

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Several investigations have shown that hemisphere has dramatic effects on movement kinematics. Movements made into the same space as the reaching hand (ipsilateral movements) are faster and more accurate than movements made across the body midline into the contralateral space. Recent work suggests that there may be some attentional advantages for targets in the right hemisphere in right-handed participants. Lueneburger et al (2000 *European Journal of Neuroscience* **12** 4107–4116) recently found that the 'gap effect' (faster reaction times when there is a short gap between fixation offset and target onset) for hand movements occurred only for right-sided targets. Their participants were right handers, so it is impossible to know if the gap effect

was related to hand preference or to moving in ipsilateral hemispace. In the current study I examined both right-handed and left-handed movements to targets varying across the hemispace in a sample of strongly right-handed participants. Contrary to Luenenberger et al, I found no evidence for larger gap effects in the right hemispace. Instead, a significantly larger gap effect was found for the left hand relative to the right hand in the strongly right-handed participants. Results are discussed in terms of cerebral asymmetries in attentional and intentional processes.

● **A network model for the inhibitory phenomena of post-attentive vision**

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A multilayer network model of post-attentive vision is proposed to account for inhibitory phenomena: inhibition of return [Posner and Cohen, 1984 *Attention and Performance X* (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 531–556], negative priming (Tipper, 1985 *Quarterly Journal of Experimental Psychology: Human Experimental Psychology* 37 571–590), attentional blink (Raymond et al, 1992 *Journal of Experimental Psychology: Human Perception and Performance* 18 849–860), and repetition blindness (Kanwisher, 1987 *Cognition* 27 117–143). Units in this model are activated in a bottom–up and top–down way. Bottom–up activation is based on inhibitory and excitatory inputs, but the inhibition is only valid for high-value input. Top–down activation, which has broad resolution and slow switching, is distributed to target candidate units. The model assumes that the asynchrony between bottom–up and top–down activations yields inhibitory post-attentive phenomena. Houghton and Tipper's [1994 *Inhibitory Processes on Attention, Memory, and Language* (San Diego, CA: Academic Press) pp 53–112; Houghton et al, 1996 *Visual Cognition* 3 119–164] model for selective attention with the inhibitory mechanism explains some experimental results of negative priming. In that model, however, gain control is associated with all properties of distractors, so inhibition is not restricted to the task-relevant distractor representation. The multilayer model proposed here provides a new explanation for the other post-attentive phenomena with the use of restricted distractor representation and asynchrony between bottom–up and top–down activations.

● **Evidence for an inhibitory explanation of transient motion blindness**

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A temporary impairment in coherent-motion detection can be induced in normal observers with a rapid serial visual presentation (RSVP) task. Essential for this effect to occur is the presence of coherent-motion distractors early in each trial. We proposed that the resulting motion blindness is caused by a delay in fully releasing the inhibition of earlier distractors. To investigate this, we used participants aged 50–70 years, because evidence exists for deficient inhibition of task-irrelevant information in this age group. If distractor inhibition contributes to impaired motion detection, poor inhibition should be associated with relatively good motion detection. Participants viewed two synchronised RSVP streams, a local stream defined by a fixation point changing colour every 100 ms, and a global stream consisting of randomly moving dots. The task was detection of a red target in the local stream (T1), which cued participants to attend to the global stream and detect a 100 ms coherent-motion episode (T2). Participants also completed the Stroop test as a measure of inhibition. The correlation between Stroop performance and motion detection was significant, indicating that a larger inhibition deficit was associated with less impaired motion detection. This suggests that transient-motion blindness is related to the inhibition of distractor motion.

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● **Are there event-related potentials to change during 'change blindness'?**

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In 'change blindness', gross changes are not seen unless at the focus of attention. As event-related potentials (ERPs) have been used to mark unconscious processes in the brain, they might reveal change detection while the subject is 'change blind'. The subjects' task was to detect whether one element of a fourteen-element ring had changed orientation by 64°. When cued to the location of possible change psychophysical performance was above threshold (87%), but when not cued, performance remained below threshold (60%). ERPs were recorded from 25 electrodes while subjects ($N = 13$) performed a similar task. When subjects were cued to the change, there was a

large amplitude increase in a late positive peak (ca 380–880 ms); but when they were uncued, this effect disappeared. Similarly, the putative visual mismatch negativity (Berti and Schröger, 2001 *Cognitive Brain Research* **10** 265–273; Tales et al, 1999 *NeuroReport* **10** 3363–3367) was also absent in the uncued paradigm. There is, however, evidence ($F_{5,61} = 2.4$, $p < 0.05$) for an amplitude increase in a frontal positive peak (ca 180–380 ms) to undetected change. However, this peak was very small and residual noise in the waveforms precludes us from positively identifying this peak as a marker for ‘sub-threshold’ change detection.

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● **Faces capture attention: a comparison of attentional cuing effects by different types of peripheral stimuli**

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We used a modified Posner cuing task to determine whether facial information can influence spatial attention. Participants performed speeded two-choice responses upon detection of the letter ‘X’ that could appear for 250 ms in the left (LVF) or right (RVF) hemifield. Prior to this target, a valid or invalid peripheral cue was presented for 100 ms (SOA = 150 ms). In experiment 1, upright faces, inverted faces, and cars were used as cues. Upright faces caused significantly larger attentional cuing effects (33 ms) than inverted faces (17 ms). Pictures of cars (28 ms) caused nonsignificantly smaller effects than faces. In experiment 2, cues were neutral, happy, or angry faces. Overall, expressive and neutral faces caused similar cuing effects. However, there was an interaction between expression and cue hemifield: RTs were somewhat slower for happy than angry faces, but only when presented to the RVF. We conclude that faces and other meaningful stimuli may capture attention to a larger degree than meaningless stimuli which are matched for visual complexity. While the results do not suggest a strong role of facial expression for attentional capture in general, they provide some support for a modified version of the ‘valence hypothesis’, according to which the two hemispheres are differentially specialised for positive and negative emotions.

● **Attention modulates recognition of depth-rotated faces but not other depth-rotated objects**

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Stankiewicz et al suggested that attention is necessary for encoding view-invariant object representations (1998 *Journal of Experimental Psychology: Human Perception and Performance* **24** 732–744). We examined this hypothesis using realistic depth-rotated face and non-face images. In a sequential matching paradigm, on each trial subjects viewed a photographic image of a face or a chair in frontal or 3/4 view while a sequence of characters flashed in its surround. In the divided-attention, but not the full-attention condition, subjects had to count the digits in the character sequence. At testing (identification), the target was presented along with two distractors of the same category, in same or different view than at learning. Recognition accuracy showed a significant three-way interaction between attention, stimulus category, and testing view. With full attention, recognition for same and different views was not significantly different for either stimulus type. With divided attention, different-view face recognition was significantly worse than same-view face recognition, but chair recognition was equivalent in both views. We postulate that attention modulates processes involved in building/storing face representations useful for recognition from depth-rotated viewpoints, possibly by augmenting surface information and fine structural details encoded. In contrast, attention may not specifically affect processes that make recognition of depth-rotated objects possible.

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● **The cue validity and compatibility effects of the irrelevant onset distractor**

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Remington et al (2001 *Perception & Psychophysics* **63** 298–307) proposed that noninformative contingent distractors showed attentional shift effect only when both validity and compatibility effects were observed. In this study, we examined two conditions not examined in their study: the effect of onset distractors on non-contingent red targets and shorter stimulus onset asynchrony (SOA). The effects of red (experiments 1 and 4) or onset (experiments 2–4) distractors on the red target were investigated with varied target salience (experiments 2 and 3), and 4 levels

of SOA (0, 50, 100, and 250 ms) were manipulated. Results of red distractors replicated the previous study in each SOA condition, including 0 ms and 50 ms SOA, showing the contingent capture effect occurred in an early time course. Results of onset distractors, however, were varied with SOA and target salience. Although validity and compatibility effects existed in some conditions, the result pattern did not meet the criterion of Remington et al (2001). These results suggest that a noninformative non-contingent onset distractor did not show attentional shift as contingent red distractor.

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● **Attentional capture without display-wide attentional setting: evidence from inattentional blindness**

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Whether a noninformative irrelevant onset can capture attention is challenged by the display-wide attentional set proposal (Gibson and Kelsey, 1998 *Journal of Experimental Psychology: Human Perception and Performance* **24** 699–706). In this study, the inattentional blindness task [IB, Mack and Rock, 1998 *Inattentional Blindness* (Cambridge, MA: MIT Press)] was adopted to exclude possible display-wide attentional sets in favour of onset. The colour task was manipulated as attentional sets, and an onset stimulus was shown in the inattentional trial to probe the capture effect. Experiment 1 showed that under the colour detection task only location of the stimulus was detectable under the colour task and letter identification task. When the luminance decrement of the colour task in experiment 1 was eliminated (experiment 2, equiluminance), both location and identity of the onset could be reported. However, neither location nor identity could be reported under the equiluminance colour task if two colours changed on the screen (experiment 3). Therefore, an irrelevant onset stimulus captures attention under contingent conditions, and primes its location when the task involves transient luminance changes under non-contingent conditions.

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● **Metacontrast masking of single letters in words and trigrams with varying loads on attention**

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Meaningful objects resist metacontrast masking. What about parts of the same object? In line with effects recently found in masking research (substitution masking, attentional blink), we studied the perception of a single letter in three-letter words and trigrams in metacontrast (MC) and paracontrast (PC) conditions. The display sequence consisted of a single letter presented first, followed by flanking letters that had a gap between them at the locus of the preceding single letter (MC). Alternatively, the flanking letters with the gap appeared first and the single letter followed (PC). SOA between the single letter and flanking letters varied from 30 to 100 ms; the number of distractor letters was also varied. The letters formed either words or trigrams presented at random positions around the fixation dot. According to the task, subjects responded by typing three or one (the single) letter(s). Single-letter identification did not differ in either MC or PC condition with no distractors. Word context decreased the effect of MC masking in short SOAs (30–50 ms) and did not improve perception in long SOAs (50–100 ms). The finding was restricted only to more capacity-demanding (higher-attentional-load) conditions.

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● **Interference by rotated distractors depends on target rotation**

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In target-selection tasks, incompatible distractors cause slower responses to the targets than do compatible distractors. This delay effect, or distractor interference reflects the processing of distractors irrelevant to the processing of targets. In this study, we investigated the effect of stimulus rotation on distractor interference in three experiments using a character-identification task. Participants were asked to identify colour-defined target characters (katakana) while ignoring distractor ones. When the targets were upright and the distractors were rotated 180°, distractor interference was not observed (experiment 1). However, when both the targets and the distractors were rotated, distractor interference was observed (experiment 2). It was also observed when only the targets were rotated and the distractors were upright (experiment 3). The results indicate that interference by rotated distractors depends on whether targets are upright or rotated. In a previous study (Nagai et al, 2000 *Japanese Journal of Psychology* **71** 395–402,

in Japanese with English abstract), we reported that the negative-priming effect did not occur when distractor characters were rotated, independent of whether targets were upright or rotated. We discuss the reason why the target rotation affected distractor interference in the present study and its relation to the negative priming observed in our previous study.

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● **Relative detectability of onsets and offsets in change detection**

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The onset of a new visual object has been shown to capture attention even when other transients simultaneously occur. However, studies of change detection demonstrate that object onsets can often go unnoticed. This appears contradictory to the idea that the human visual system is particularly sensitive to the onset of new objects. Assessing the relative detectability of onsets compared with other visual transients within a change detection procedure may help reduce this contradiction. We report the results of four experiments in which we investigated the ability of onsets to capture attention compared with offsets. In experiment 1, participants viewed continual alternation of images containing abstract shapes one of which appeared and disappeared. We assessed the likelihood that participants would detect change following an onset or offset frame. In experiment 2, the one-shot method was used and we assessed observers accuracy for detecting onsets and offsets. In experiment 3, we measured response time to the detection of onsets and offsets. In experiment 4, we assessed whether the results obtained in experiments 1–3 would replicate when images of real-world objects were used. Results showed that onsets are less susceptible to change blindness than offsets.

● **Shifts in feature-based attention as a result of spatial cueing: support for location dominance in attentional selection**

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Recent studies on the different modes of attentional selection have suggested that feature-based attention may be mediated by spatial location. Here we provide evidence that supports this idea, and we investigate a possible time course for such mediation. We designed psychophysical tasks to study whether a shift in spatial attention gives rise to a shift in feature-based attention towards the features present at the attended location. In one experiment, subjects looked at a central square that disappeared 200 ms after trial onset. After a gap of 200 ms, a peripheral square appeared 17 deg to the right or left of fixation and acted to capture spatial attention. The peripheral square was extinguished 150 ms later, after which a second foveal square appeared for 50–150 ms. Subjects maintained fixation and compared the colours of the two foveal squares regardless of the colour of the peripheral one. We found that the colour of the peripheral square influenced colour perception at fixation, with the effect being strongest approximately 100 ms after the onset of the final foveal square. When the peripheral square was replaced with a parafoveal ring to avoid any explicit summoning of spatial attention, no similar effect seemed to occur.

● **Its easier to track moving items if they are collinear with their direction of motion**

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How can the visual system track multiple moving objects through time? We propose that attending to trajectories is facilitated by mechanisms similar to the association fields proposed for contour extraction (eg Field et al, 1993 *Vision Research* 33 173–193). Here, we investigate one prediction of this spatiotemporal association field hypothesis: objects aligned with their heading should generate stronger forward associations and better tracking than stimuli whose motion is orthogonal to their orientation.

Stimuli were Gabor patches (spatial frequency, 0.5 cycle deg⁻¹) on a grey background. There were ten items on each trial. Five items were cued at the start of the trial, and five observers tracked them for 10 s. Items bounced off display edges and each other. Velocity varied inversely with distance to other items. In separate blocks, items were either collinear or orthogonal to their headings. When motion ceased, observers identified the cued items. As predicted, mean accuracy was significantly higher ($t_5 = 5.82$, $p < 0.005$) in the collinear condition (74.7%; SEM, 3.9%) than in the orthogonal condition (67.1%; SEM, 2.7%). Spatiotemporal association fields may form the basis for a theory of trajectory prediction in multielement visual tracking.

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● **Overwriting of visual short-term memory (VSTM) in change blindness**

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Previous research has shown very steep set-size effects in single-target change detection (across an ISI) for arrays of multiple Gabor patches, suggesting a low-level explanation of change blindness. Loss of information in such tasks was investigated by manipulating the timing of spatial cues. The task required a decision whether a specific target had increased or decreased in spatial frequency. Each frame contained 1–8 Gabor targets and lasted 100 ms. The ISI was 2000 ms. Distractors changed along with targets, so that global judgments of spatial frequency were uninformative. If the target was cued before the first display, thresholds were low, and equivalent to single-target thresholds. For cues after the end of the first frame, accuracy declined only gradually with cue delay (up to 2000 ms), but declined dramatically (and set-size effect increased) for cues placed after the second frame (post-cues). A noise mask affected performance only if presented immediately after the first frame, selectively disturbing iconic memory. A Gabor mask increased thresholds for as long as 500 ms after the first frame, when displayed before a mid-ISI cue. The results support an overwriting explanation of change blindness. The overwriting effect was graded, dependent on set-size, and consistent with limited processing resources. [Supported by the Wellcome Trust.]

GLOBAL MOTION

● **Local and global movements of an element strongly influence its perception**

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We investigated whether the presence of local movement inside an object influences its perceived global motion, and, vice versa, whether the global motion of an object influences the perceived local motion of structures inside the object. In both psychophysical experiments, two Gabor patches moved downwards along straight paths on a computer monitor. In addition to moving vertically, they could also move horizontally, either towards or away from each other. The sinusoidal patterns of the Gabor patches could also move relative to their boundaries, either inwards or outwards. In the first experiment, subjects had to detect whether the two Gabor patches were globally moving towards or away from each other. In the second experiment, they had to detect whether the sinusoidal patterns of the Gabor patches within their boundaries were moving inwards or outwards. In both experiments, subjects showed large biases. These biases depend solely on the horizontal components of the motion. Although they were specifically instructed to look at the motion of the Gabor patches as a whole (experiment 1) or at the motion within the Gabor patches relative to their boundaries (experiment 2), subjects appeared to always track the absolute movement of simple features within the Gabor patch.

[Supported by NWO.]

● **Perceived global velocity is strongly influenced by motion inside the moving elements even when their boundaries are well-defined**

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In previous research, we found that the perceived global velocity of Gabor patches is strongly influenced by the local motion of the sinusoidal patterns of the Gabor patches relative to their boundaries. We hypothesised that the large biases would gradually disappear when the boundaries of the patches became more prominent. With this in mind, we did the following experiment. Two Gabor patches moved downwards along straight paths on a computer monitor. The patches could also move horizontally, either towards or away from each other. The sinusoidal patterns of the Gabor patches could move relative to their boundaries, either inwards or outwards. We created four levels of the sharpness of the boundaries: a full Gabor patch, the same sinusoidal pattern with a sharp boundary, and two levels of sharpness in between. Subjects were instructed to detect whether the two Gabor patches were globally moving towards or away from each other. The results show that the prominence of the boundary is indeed of influence. However, even with the sharpest boundaries, biases do not disappear completely. Thus, even when the boundaries of the moving patches are well-defined, subjects appeared to be influenced by the absolute movement of simple features within the Gabor patch.

[Supported by NWO.]

● **Depth-ordering cues gate motion signal propagation**

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We have shown (2002 Vision Sciences) that depth-ordering cues can alter the perceived direction of unoriented moving features. Similar observations with oriented features have been explained by depth cues allowing identification and suppression of 'extrinsic' line-terminator motion, yet this explanation cannot account for our result. Here we tested an alternative hypothesis. A test field (moving dots at zero disparity) was viewed through a central diamond-shaped aperture, defined by four panels in one of two depth configurations: (i) upper-left and lower-right panels in front (NEAR), lower-left and upper-right behind (FAR), and (ii) vice versa. Two inducing (zero disparity) dot fields were placed in either NEAR or FAR panels (so that the test field was between them) and moved either in the same or opposite direction as the test field. Motion coherence in the test field was varied from 0% to 50%. Naïve observers reported the motion direction of the test-field dots. Motion was reported in the inducer direction significantly more often with inducers in the NEAR panels than with inducers in the FAR panels. This result suggests that depth cues affect motion interpretation by allowing propagation of motion signals in the direction of NEAR but not FAR surfaces.

● **Prior monocular information can bias motion perception**

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Previous studies of the motion-aperture problem have shown that the direction of grating motion can be biased by using binocular disparity to designate borders of the aperture as intrinsic (belonging to the grating) or extrinsic (resulting from occlusion of the grating). Subjects report motion in the direction of the extrinsic border, as if the grating was extended and moving underneath an occluding surface. Here we investigate whether prior monocular depth information, defined by structure-from-motion, can bias the perception of motion of a subsequent motion-aperture test stimulus in a similar manner. We presented an aperture stimulus that rotated about its vertical and then horizontal axes, revealing the depth (intrinsic and extrinsic) relationships of the aperture borders. The grating then moved, and subjects reported the direction of perceived motion. The test stimulus contained no information about the depth ordering of the scene. We found that subjects' responses shifted toward reporting motion in the direction of the occluding surfaces, consistent with the intrinsic-extrinsic hypothesis. These results indicate that prior scene information, not just depth information explicitly defined in the test stimulus, can be used to help solve the motion-aperture problem.

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● **Motion boundaries between different complex motions**

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The perception of motion boundaries created by a breakdown in the uniformity of the motion structure was studied. Random-dot kinematograms of limited lifetime (100 ms) displaying complex motions with constant speed were used. Presenting different motion types in two spatially adjacent regions of the display changed the direction of the motion and the directional contrast across the boundary. In experiment 1, the observers had to detect in which of two sequentially presented intervals the display contained a discontinuity in the motion structure. The threshold for motion boundary detection was about 40–60 deg for cardinal motions and about 90 deg for spiral motions. In experiment 2, the ability to localise the motion boundary was studied. Only the directional contrast between the motions, not their type, affected the performance. The localisation of the discontinuity was worse when it was formed by dots approaching the boundary at some angle than by dots receding from it. The results may be interpreted as an indication that the detection and localisation of motion boundaries due to nonuniformity of the motion structure are based on motion detectors with different directional tuning. The ecological significance of motion boundaries formed by changes in the motion structure for self-motion is considered.

● **Effect of edge cues on global speed perception**

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The perceived speed of radial motion (expansion) is overestimated relative to that of translation (eg Matthews et al, 1999 *Vision Research* **39** 3692–3701). Bex et al (1998 *Journal of the Optical Society of America A* **15** 769–776) reported that the perceived speed of a grating viewed through four apertures is overestimated if the grating orientation in each aperture is orthogonal to that

in adjacent apertures (expansion), compared to configurations in which grating orientation is identical across each aperture (translation). They attributed this to a two-stage system of motion integration: local velocity estimates are combined by a global mechanism able to represent complex configurations of local signals. Changing the orientation of indentations of an aperture can predictably alter the perceived direction of motion and therefore apparent speed, although the grating orientation remains the same (Badcock, McKendrick, Ma-Wyatt, submitted). We used indented apertures to create apparent radial motion when grating orientation was identical in all apertures. The speed of apparent radial motion was overestimated compared to translation. The magnitude of the increase was consistent with recent findings, indicating that the speed of complex motion is determined by averaging local-speed estimates.

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- **Size affects grouping in apparent motion**

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Pelli (1999 *Science* **285** 844–846) has shown that size significantly affects the perception of shape. I used the Ternus display to test the effect of size on motion grouping. Generally, element motion is seen at short ISI durations and group motion at long ISI durations. The ISI for 50% group motion provides an index of strength of group motion. Reversing the polarity of the end elements was found to increase this index value, consistent with earlier findings that reversing contrast polarity enhances element motion. The situation is different if all elements fall within 0.5 deg. At constant polarity, 100% group motion responses were found at all ISIs, as Petersik (1986 *Perception & Psychophysics* **39** 445–446) reported when all elements fell within 15 min of arc. Reversing the polarity of the end elements led to predominantly element motion, regardless of ISI. These results indicate that size has a powerful influence on motion grouping.

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- **Global, but not relative, motion detection is impaired in visually deprived cats**

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We investigated global motion detection in binocularly deprived cats and control cats. The cats were trained in a two-choice free running apparatus for a food reward. The positive stimulus was a moving random-dot pattern with all dots moving in one direction, the negative stimulus was the same random-dot pattern but stationary. The binocularly deprived cats were severely impaired in detection of global motion stimulus as compared with the control cats. In contrast, their level of performance in a simple relative-motion-detection task (one square) did not differ from that in the control cats. However, in a more complex relative-motion-detection task (two squares) the performance of the binocularly deprived cats was impaired. The deficit in the detection of global motion in binocularly deprived cats may be due to impairments of their Y pathway.

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- **Chromatic global motion processing: two mechanisms?**

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We investigated the interaction of colour and motion cues for global motion integration across space. At the last ECVF (Ruppertsberg et al, 2001 *Perception* **30** Supplement, 59) we presented global motion detection thresholds as a function of chromatic contrast in the equiluminous colour space [S vs (M–L) space]. Eight out of ten observers were not able to perform the task for S-cone isolating stimuli. In all other colour directions, the thresholds were determined by the stimulation of the red–green mechanism. Using the same stimuli, ie random-dot kinematograms with 300 coloured Gaussians, each 0.22 deg, moving at 1 deg s^{−1} presented on an equiluminous grey background (50 cd m^{−2}) at 40% coherence level, we have established observers' individual equiluminance by heterochromatic flicker and obtained results comparable with those previously reported. This finding rules out possible luminance artifacts. In a further study we increased the dot size from 0.22 deg to 0.86 deg and found that participants could extract global motion for S-cone isolating stimuli. We conclude that the contribution of the cone input to global motion extraction in the equiluminous plane is dependent on size.

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● **Perceiving a fragmented barber-pole illusion**

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The barber-pole illusion can be regarded as a tool for studying the mechanisms of motion integration in the human visual system that has to combine the local-motion signals arising from boundary regions and from the central region of the aperture in order to produce a coherent motion percept. Indeed, changing the stimulus geometry affects the tendency to perceive motion along the major axis of an elongated aperture. When the orientation of gratings moving behind a rectangular aperture and its aspect ratio are varied independently, perceived motion direction can be shown to depend on both the cycle ratio (like terminator ratio for line gratings) and the grating orientation that is responsible for perpendicular motion components most distant from the boundaries. Since a simple cycle-ratio explanation cannot fully account for the perceived effects, the illusion should be stronger when the circumference of the apertures is increased while the overall stimulus area and shape are kept constant. This prediction was tested experimentally by fragmenting the aperture into a set of smaller apertures of identical shape and constant cumulative area, and measuring perceived direction. As expected, the strength of the illusion increases with the number of aperture fragments, ie the ratio between circumference and overall area, which determines the relative contributions from boundary regions. The distribution of local-motion signals can be precisely manipulated in the fragmented barber-pole stimulus, allowing us to study exactly how local signals are combined in cortical motion processing.

● **A Fourier approach to the Ouchi-type anomalous-motion illusion**

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An illusory sliding motion is perceived in a rectangular checkerboard pattern that is surrounded by an orthogonally oriented pattern (Ouchi illusion: Spillmann et al, 1993 *Investigative Ophthalmology & Visual Science* **34**(4) 1031). This illusion has been explained in the image space by the bias toward the normal motion vector of the longer edge (Fermüller et al, 2000 *Vision Research* **40** 77–96; Mather, 2000 *Perception* **29** 721–727). We created a variant of the Ouchi figure by replacing the black rectangles with thin lines, which produces a comparable motion illusion. This figure has the advantage that we can mix up the spatial-frequency spectrum by randomly shifting each line element, without a significant disorder of the edge structure. A rating experiment revealed that the illusion is diminished as the line shift becomes larger, that is as the power at the fundamental spatial frequency decreases. The results suggest that the Ouchi illusion will be further understood in Fourier spatial-frequency space. The fundamental components (and possibly several harmonics) are considered crucial. The illusory relative motion must be related to the directional biases for type II plaids (Ferrera and Wilson, 1990 *Vision Research* **30** 272–287), which arise in different directions in the inner and the outer areas of the Ouchi figure.

● **Are pattern cues used to precisely specify motion direction?**

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The direction a pattern appears to move is influenced by its spatial structure. One simple pattern, the sinusoidal grating appears to move orthogonally to its orientation when viewed in a circular or square aperture. However, the well-known aperture effect indicates that the true direction of motion is ambiguous. A series of experiments (and some demonstrations) are presented that show that the perceived direction a grating moves is more dependent on the edge orientation than the grating orientation. Rectangular and circular apertures with local indentations alter the perceived direction of motion so that it closely matches the orientation of the aperture indentations. The experiments are consistent with the suggestion that the motion system usually employs pattern information to help to precisely determine the perceived trajectory. These findings argue against the independence of form and motion processing, and suggest a useful alternative approach to understanding human motion processing.

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● **Illusory surfaces have long-range effects on motion integration**

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When an object crosses the visual field, its direction of motion is ambiguous, because the local signals of motion are kinematically indeterminate (aperture problem). The visual system can tackle this problem by integrating the motion signals across space. We studied the long-range interactions between local motion signals and the stimulus global spatial context. To test the integration of motion components, we measured speed-discrimination thresholds for stimuli with two motion signals (using a 2IFC paradigm) and used the thresholds as an index of motion sensitivity. Two Gabor patches were presented in each interval, but in some conditions one of them appeared enclosed by illusory contours. Thresholds were higher when one signal was perceived on top of an illusory figure. Control conditions in which illusory figures did not form ruled out other possible explanations. Another control condition compared the configurations when only one Gabor patch was present. We found no differences between conditions in this case and take this as further support that the effect is specifically due to integration. We conclude that the formation of surfaces and depth stratification can interfere with the integration of local motion signals because integration on the same depth plane is stronger.

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● **The interaction between element orientation and perceived direction of motion**

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Three experiments were performed to investigate the relationship between orientation of elements and perceived direction of motion. A competing-motion technique was used with two frames presented in alternation. Elements were differently oriented lines (experiment 1); ellipses undergoing luminance changes (experiment 2); elements undergoing shape and position changes (experiment 3). Results show a preference for collinear motion (motion between elements oriented along the motion direction). A similar result was found by Werkhoven et al (1990 *Perception & Psychophysics* 47 509–525), who suggested an explanation based on luminance-sensitive receptive sub-fields. The preference for the collinear direction of motion could not be ascribed to perceived spatial proximity (experiment 1); it was not dependent on luminance distributions (experiment 2); but was determined by the orientation of the element presented in the first frame (experiment 3). A systematic preference was found for horizontal motion paths. Data are interpreted in terms of perceptual organisation and ecological validity.

● **The effect of spatiotemporal factors on acceleration perception**

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Human observers do not perceive motion acceleration accurately. Slightly accelerated motion is perceived as linear, ie as motion having constant velocity (Runeson, 1974 *Psychological Research* 37 3–23). Motion acceleration or deceleration is perceived only when velocity change is large. The object of this study was to examine how motion duration, travelled distance, and average velocity affect the perception of acceleration. A small target travelled 4, 8, or 16 deg of visual angle in 400, 800, 1600, or 3200 ms. The deceleration threshold, the acceleration threshold, and the point of subjective motion linearity were determined for each condition. The point of subjective linearity was affected by duration and travelled distance, but not by average velocity. Motion with short duration and over short distances had to be linear or slightly decelerated to be perceived as linear. With increase of duration or distance, motion had to be increasingly accelerated to be perceived as linear. Detection of velocity change was poorest at the shortest motion duration and the shortest distance. The results suggest that separate spatial and temporal integration processes influence the perception of velocity and acceleration.

PERCEPTION AND ACTION

● **Shifts in fast reaching movements due to motion recover after a delay**

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The endpoints of fast-pointing movements to the remembered location of a stationary object can be shifted when other objects in the scene are moving; the pointing movements are deviated in the same direction as the nearest retinal motion signals. Here we investigated whether the accuracy of pointing movements varies as a function of the delay between the presentation of the target stimulus and the initiation of movement. A small stationary target was presented for

~30 ms while a vertically drifting stimulus was presented ~10 deg away. An auditory start signal was presented between 0 ms and 1800 ms after the target flash disappeared, cueing observers to point as quickly as possible to the remembered position of the target. When movements were made immediately after the target presentation there was a significant deviation of movement endpoints in the direction of the preceding motion; however, when movements were delayed by ~1800 ms, there was no deviation—pointing movements were accurate. The results indicate that the representation of remembered target location is influenced by visual motion but that there also must be another source of information allowing veridical target location to be recovered after a sufficient delay.

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● **Effects of the Ebbinghaus illusion on grasping in a virtual environment**

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It is an open question whether the Ebbinghaus (or Titchener) illusion affects perception more than grasping. Evidence for a stronger effect on perception has often been based on a perceptual task called 'manual estimation'. We compared manual estimation to a standard perceptual measure as well as to grasping. Virtual target discs (diameter: 38, 40, or 42 mm), surrounded by small or large discs (diameter: 10 or 58 mm) were displayed stereoscopically on a monitor, generating the Ebbinghaus illusion. In the grasping task, ten participants grasped the target. Haptic feedback was simulated by two robot arms (PHANTOM[®]). In the manual-estimation task, participants indicated the size of the target using index finger and thumb (without seeing their fingers). In the standard perceptual task, they adjusted a comparison to match the target. We found illusion effects on manual estimation (2.3 mm, SE 0.45 mm) which were larger than both the grasp effects (1.1 mm, SE 0.29 mm) as well as the effects on the standard perceptual measure (0.7 mm, SE 0.11 mm). This suggests that manual estimation shows relatively large illusion effects.

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● **When the hand is as blind as the eye**

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Research has put in question the view of a single and all-inclusive visual analysis. For instance, a dichotomy between vision-for-perception and vision-for-action has been suggested. In addition, change-blindness experiments, where observers fail to notice significant changes to the visual scene, indicate that humans do not construct an exhaustive representation of the visual world. Previously, we found that change-blindness can extend to affect motor responses in a simple reaching task, requiring observers to reach for bar stimuli presented on a computer display (Sowden and De Bruyn, 2001 *Perception* 30 Supplement, 111). Here we extended this work to require observers to reach for real 3-D stimuli. Observers reached for bars presented sequentially, using a rotating turntable. Presentation of each pair of bars was separated by a blank display, analogous to the 'flicker' displays often used in computer-based change-blindness experiments, which served to induce change blindness to changes in bar size. In agreement with our previous work on 2-D stimuli, here we found that observers' grip aperture to 3-D stimuli was scaled only when changes in visual size were consciously perceived. Thus, our results confirm that change-blindness can extend to the motor system and provide one instance where the vision-for-perception, vision-for-action dichotomy breaks down.

● **When two eyes are better than one in prehension**

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Previous research suggests that binocular vision plays an important role in prehension. A number of studies have demonstrated changes in the kinematics of prehension when binocular vision is removed. Complementary studies have begun to explore what binocular information is used and how this information is exploited by the human nervous system. The present series of experiments was conducted in order to explore further when binocular information is advantageous in prehension. Three experiments were employed which varied binocular/monocular viewing in selectively lit conditions. Our research suggests that the nature of the advantage conferred by binocular vision depends upon task conditions. One constant advantage of binocular vision

appears to be in its provision of on-line information regarding the position of the hand relative to the target. In reduced cue conditions (ie where a view of the target is lost after initiation of the movement), binocular vision appears to be particularly useful in the initial programming of reach distance. These results are a step towards establishing when the removal of binocular vision affects prehension.

● **Visual cues to airspeed and altitude in simulated flight over textured terrain**

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In the context of flight simulation, edge rate and optic flow are two of the major cues to airspeed and altitude. These variables can, however, be difficult to quantify in the case of flight over realistically textured terrain. We have measured perceived airspeed and altitude over textures of varying density, and have attempted to correlate those measures with quantifiable properties of the textures. Observers attempted to actively maintain either their initial airspeed over terrains whose texture density varied, or their initial altitude over terrain whose height varied. The input texture densities varied by a factor of more than 64 000 elements m^{-2} . As displayed, the spectral content of the textures approximated that of natural terrain. Flight was simulated with a high-performance PC-based image generator (MetaVR Inc.), and the terrains were displayed across three channels of a wide-field, CRT rear-projection display (180 deg horizontal \times 63 deg vertical). The RMS error for altitude maintenance varied from about 2.0 m to 4.0 m from the lowest to the highest terrain density, and was significantly greater than that found for perceived airspeed. This finding is consistent with previous research that has shown altitude maintenance to be dependent on changes in the size of terrain texture elements as well as on edge rate and optic flow.

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● **Effects of backward-masked stimuli on pointing movements**

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Stimuli which are completely masked for conscious perception can still show robust effects on motor responses. Schmidt (2002 *Psychological Science* **13** 112–117) found that masked stimuli affected pointing movements. However, there was a direct compatibility between the position of the imperative stimulus and the goal of the pointing movement. Here, we eliminated this compatibility by using imperative stimuli that only symbolically coded the direction of the pointing movements. Successions of primes and imperative stimuli were shown (duration prime 31 ms, ISI 42 ms, target 83 ms). Primes and imperative stimuli were squares, oriented at 0° or 45°. Twenty-two participants (a) discriminated amongst the primes, (b) responded to the orientation of the imperative stimulus by pointing to a left or right target, and (c) responded by pushing a left or right button. Participants were not able to discriminate amongst the primes ($d' = 0.07$, $p = 0.10$). Nevertheless, the reaction times differed between congruent and incongruent conditions (51 ms, $p < 0.001$), as did the pointing trajectories. Completely masked stimuli can affect pointing movements even if there is no compatibility between the location of the imperative stimulus and the goal of the pointing movement.

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● **Misperceived length influences pointing**

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Illusions produce biases in the analysis of certain aspects of visual information. Tasks are therefore influenced by visual illusions only if they depend on the aspect that is affected by the illusion. We investigated the influence of the Brentano version of the Müller-Lyer illusion on pointing. Subjects made pointing movements from several starting positions (an endpoint of the illusion or a position outside the figure) to the centre of the illusion. Our hypothesis was that the illusion only influences length information, so an effect was expected on pointing movements within the figure (for which length could be relevant), and not for movements from outside the figure. In one experiment, the hand was visible during the pointing movement but the stimulus disappeared as soon as the hand started to move. In two others, the stimulus was seen through a mirror so that the hand was not visible, and the stimulus either disappeared once the hand moved or it

remained visible. The illusion influenced movements from the endpoints of the figure to its centre, but not those from outside the figure. Visibility of the hand and stimulus made no difference, confirming that it is the relevance of perceived length that is critical.

- **Motor asymmetries in the visual space for action**

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We investigated the anisometry of the visual space for action and its motor origin by comparing the performance of left-handers and right-handers in a distance elongation task. As soon as the subjects touched with a stylus a digitiser tablet hidden by an opaque panel, a point was displayed on a PC screen to form, together with the central fixation point, the stimulus distance. Participants had to double the given distance from its central endpoint to the periphery quickly, either with visual feedback (VF) or with no visual feedback (NVF), by moving the stylus on the tablet with their preferred hand. Three different stimulus distances (1.5, 6, 12 cm) presented with eight different stimulus orientations (from 0° to 315° in steps of 45°) were used. We found that stimulus distance affected significantly both accuracy and precision of the subjects in doubling the given distance. Participants consistently overshoot the elongation distance for the shortest stimuli, undershot it for the longest ones, whereas there was no bias for intermediate stimuli. Right-handers were more accurate when they doubled distances rightward in the VF condition and and leftward in the NVF condition. The precision in doubling the given distance increased as the stimulus distance increased. Subjects' accuracy in reproducing the distance orientation was influenced by the stimulus orientation only in the NVF condition. In the right-handers, the main axes of the visual space for action were rotated counterclockwise. Overall, participants were more accurate and precise in the VF condition than in the NVF condition. Differences between left-handers and right-handers suggest that movement modulates the visuospatial processing that mediates action.

- **Predicting object shape from movement parameters**

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It has been shown that during grasping the grip aperture correlates with the object's size. It is unclear, however, how this correlation develops over time. The same applies for the correlation between the orientation of the hand and that of an asymmetrical object. We therefore measured the fingertip positions of seven right-handed subjects while they picked up 10 cm tall cylinders with an elliptical base. One axis of the elliptical base was 5 cm long while the other ranged from 2 cm to 8 cm in steps of 1 cm. The cylinders were placed in front of the subject, at a distance of either 30 cm or 60 cm, in one of six evenly distributed orientations. The hand started 30 cm to the right of the nearer cylinder position. We found that the correlation between the instantaneous grip aperture and its final value increased linearly during the movement. The correlation between the hand orientation and its final value increased initially much faster: apart from one subject the correlation already exceeded 70% at 30% of the total distance travelled. We conclude that grip aperture and hand orientation can be used to predict the intended final pick-up positions when grasping an object.

- **Behavioural dynamics of route selection during walking**

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How do people select a route through a complex scene? We show that route selection emerges from the on-line visual control of walking. In previous research, we developed a dynamical model of steering and obstacle avoidance. Goals behave as point attractors of heading, and obstacles as repellers, whose strength depends on distance and heading angle. In the present experiments, we used the model to predict routes through configurations of obstacles. Participants walked to a goal in a 12 m × 12 m virtual environment while wearing a head-mounted display (60 deg horizontal × 40 deg vertical). Head position was measured with a sonic/inertial tracking system (50 ms latency). Our findings are as follows. (i) One obstacle: participants switched from an 'outside' to an 'inside' path as predicted, characterised as a tangent bifurcation. (ii) Two obstacles: they switched from an outside, to an inside, to the middle path—the same sequence as the model. (iii) 'Cul-de-sac' or local minimum: participants were more likely to cut through an arc of obstacles as its length and gap width increased, similar to the model. Route variations are captured by adding noise to the model. Route selection can thus emerge on-line from the steering dynamics, making explicit path planning unnecessary.

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● **Heading in the right direction: does the location of the centre of outflow matter?**

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Walking paths to a close target with subjects wearing displacing prisms are typically curved, suggesting that the (displaced) visual direction of the target is more important than optic flow in controlling locomotion [Rushton et al, 1998 *Current Biology* 8 1191–1194; Rogers and Dalton, 1999 *Investigative Ophthalmology & Visual Science* 40(4) S764]. However, the centre of outflow and other singularities of the flow field are displaced away from the fovea when prisms are worn, which might not be optimal for deriving the point of impact. We compared walking paths in three situations, with subjects: (i) wearing prisms and fixating the intended target; (ii) not wearing prisms, but with gaze directed to one side (causing the centre of outflow to be displaced away from the fovea); (iii) wearing prisms and with gaze directed to one side (bringing the centre of outflow back onto the fovea). Using a sample of ten observers, we found no significant differences in the extent of path deviation between conditions (i) and (iii), suggesting that having the centre of outflow displaced away from the fovea is of little consequence. Second, there were no significant differences between conditions (i) and (ii), suggesting that the prisms themselves are not a source of artifact.

● **Effect of global perspective jitter on visually induced postural sway**

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Previous research has shown that adding global perspective jitter to radial flow decreased vection onsets and increased vection durations (Palmisano et al, 2000 *Perception* 29 57–67). This was a surprising finding because the visual jitter in these displays simulated random horizontal/vertical impulse self-accelerations which should have produced sustained visual–vestibular conflict (previously thought to always impair vection). We examined whether there was also a jitter advantage for visually induced postural sway. While viewing the visual displays, observers stood on a Kistler force platform with two optical displacement sensors (MEL Mikroelektronik GmbH M5/200) aligned to the centres of their backs and to the midlines of their right calves (each device was sampled at 200 Hz). This enabled sway amplitudes and frequencies to be calculated along both their sagittal and coronal axes. We found that adding global perspective jitter to radial flow increased both fore–aft and lateral sway in our standing observers. On the basis of these results, we conclude that the horizontal/vertical jitter not only increased the vection in depth induced by radial flow, but it also induced additional horizontal/vertical jittering vection.

● **Effect of observer's translation on the spatial memory of a target within walking distance**

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We investigated how translation of the observer's position affected the behavioural characteristic of pointing to targets within walking distance. Subjects observed a target 2 m ahead for 2 s. During a delay of 3 s, they moved their own bodies either to the right or to the left, either 40 cm or 80 cm, then pointed to the remembered target location. Subjects showed pointing errors displaced toward the body position after translation irrespective of the translation distance. The pointing error could be related to the weighted sum of two types of pointing error. One type is a linear function of the distance from the translated body position to the target location. This type of error would occur in the transformation process solely from the egocentric spatial representation of the target, with reference to the translated body position, to the final pointing position. The other is a displacement toward the frames of target presentation area. This type of error would occur in the transformation solely of the allocentric representation with reference to the frames. Depending on whether subjects did or did not move, the weight of the error due to egocentric spatial representation varied.

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● **Motion and colour latencies are task-dependent**

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It has been suggested that we are aware of some visual attributes more quickly than others (Moutoussis and Zeki, 1997 *Proceedings of the Royal Society of London, Series B* 264 393–399). Also, there is evidence that visual information for perception is processed separately from that for action [eg Milner and Goodale, 1995 *The Visual Brain in Action* (New York: Oxford University Press)].

We investigated whether processing time shows an interaction between attribute and the type of task being performed. Two objects rotated around a central fixation point. After a random time interval one object changed colour or speed. Shortly afterwards, the other object changed colour or speed. There were three response conditions: (a) reaction times: press a key as soon as any change is detected; (b) pointing: 'squash' the object that changes first; (c) perceptual choice: indicate with key presses which object changed first. High and low salience colour and speed changes were used and the time between the two changes was varied from 0 to 200 ms. A simple model in which each event is processed independently provided an excellent fit to the data for all three response conditions. Increased salience produced a consistent decrease in processing time. There was an interaction between attribute and response condition.

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- **Colour perception in the sensorimotor contingency theory**

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The sensorimotor contingency theory hypothesises that our experience of a rich, colourful, environment derives not simply from the information originating from sensory input channels, but also from the laws that these signals obey when the observer or the stimulus move. In one experiment, subjects are shown a coloured bar, which either moves outward from the fovea, or inward from the periphery. If the stimulus changes colour on stopping, subjects generally see it as being the same colour as they previously saw in central vision, confirming that our perception of colour is affected by prior visual exploration. A second test of the theory concerns the implication that modifications of sensorimotor laws must result in changes in subjective experience, with these changes being stronger when the observer is active in sensory exploration. We present results from an experiment where we adapted subjects to new sensorimotor laws between colour and eye movements. During an adaptation phase, subjects pursue a figure on a screen. Figure or screen colours are modified depending on gaze direction. Tests of position-dependent colour judgments before and after the adaptation phase demonstrate effects of the adaptation.

- **Limitations to visual detection of suprathreshold patterns**

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Measurements of detection thresholds for gratings in noise have revealed that human performance is limited by internal noise and by sampling inefficiency. Many common visual tasks involve detection of targets that are above threshold contrast, and we sought to determine the limits to visual detection in such conditions. Simple reaction time (RT) was measured for detecting a flashed Gabor patch in dynamic Gaussian white noise. The ideal observer in a simple RT task must form an estimate of the time of arrival of the signal and hit the button at that time. For an ideal observer, the variance of this time-of-arrival estimate increases linearly as the variance of the external noise increases. The human observer's RT variance behaves in a similar way, but humans have low sampling efficiency and add internal noise. As the signal contrast increases, the internal noise remains constant, but the sampling efficiency increases. Thus observers in everyday situations may detect visual patterns better than might be expected from extrapolation of threshold data.

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- **Biases in clock reading**

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Crawford et al (2000 *Cognition* 75 209–235) demonstrated systematic biases toward diagonal positions when observers estimated from memory the location of stimuli presented around a central rectangle. We investigated whether the same biases were present in a situation involving estimates of clock-hand positions around an imagined clock face. Three subjects carried out two angular estimation tasks. In task 1, a circle was presented with a single mark on it. Participants estimated the time that this represented on a clock face (in minutes past the hour). In task 2, they were given a number (of minutes past the hour) and required to point to the corresponding position on a circle. The pointing position was recorded via a touch screen.

Errors in the estimates of clock-hand position (task 1) and pointing positions (task 2) both showed systematic biases away from the vertical and horizontal axes. The similarity between

results from the two tasks suggests that a common spatial representation is responsible both for perceptual and for motor responses. Our results are consistent with Crawford et al's findings and are discussed in relation to a model of categorisation in which biases are explained by increased sensitivity around category exemplars.

- **Visual perception and priming by higher-order social concepts**

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The object of this research is to introduce Bargh's (see Bargh and Chartrand, 1999 *American Psychologist* 54 462–479 for a review) concept of automaticity into the study of processing of visual information. We refute one of Bargh's assumptions within his automaticity research. Specifically, he implies within his perception–behaviour link model that perception of visual information is stable. Two studies we conducted purport to demonstrate the influences of pre-existing schemas and higher-order concepts on basic perception of visual stimuli. We conclude by suggesting further research into the effects of priming on visual perception and its important relationship to the evaluation of higher-order social behaviours.

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FORM AND SHAPE

- **The half-moon illusion, sun-ray parallelism, and perspective**

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The half-moon illusion is a striking violation of the rule that the shadow line on a sphere that is illuminated by a spherical light source is perpendicular to the line joining the centres of the spheres. Namely, if you draw a normal to the shadow line from the centre of the lit sphere—call it the 'middle-shadow normal'—this line will pass through the centre of the light source. Yet, in the real world, the middle-shadow normal of the half-moon misses the sun dramatically, as you can see for yourself next time there is a half-moon. Brian Rogers pointed out this illusion, which he termed the 'new moon illusion' to Stuart Anstis, who discussed it [1991 *Representations in Vision* Eds A Gorea et al (Cambridge: Cambridge University Press) pp 281–282], and gave a brief explanation, which he attributed to Mike Swanston. I present a simple geometrical explanation based on the parallelism of the sun rays. Furthermore, I explore the question how the ancients conceived the parallelism of sun rays, despite their convergence to the sun. The parallelism of sun rays was used heavily by ancient geometers. Most famously, Eratosthenes used it to get a rather accurate estimate of the Earth's circumference in 230 BC.

- **Contextual effects on shape processing in the human visual cortex**

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The detection of visual targets against their background is critical for shape perception. The human lateral occipital complex (LOC) has been implicated in the processing of shapes. We tested whether the LOC processes information about the context (background) of shapes. We addressed this question by using event-related fMRI adaptation in which lower neural responses are observed for two identical than for two different consecutively presented stimuli. The stimuli consisted of displays with a closed target contour of collinear Gabor elements embedded into a background of randomly oriented Gabors. There were four different conditions: (i) identical image, where the two stimuli in a trial were the same; (ii) different shape, where the target shape was different; (iii) different context, where the target shape was the same but the background was different; (iv) completely different, where both the target shape and the background were different. We observed adaptation in the LOC when the target shapes were presented in the same background, but no adaptation when they were presented in different backgrounds. These findings suggest that neural populations in the LOC process information about the context of visual shapes.

- **Reflecting a picture of an object: what happens to the shape percept?**

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Making a picture of a three-dimensional object results in losing the third dimension, namely the distance range. Yet, pictorial depth cues make a three-dimensional interpretation possible.

The three-dimensional interpretation of the depicted object is called the pictorial relief. An object photographed from several viewpoints results in different pictures varying in structural information. However, mirror-image versions of a photograph depicting an object from one (arbitrary) viewpoint, contain the same structural information. We investigated the influence of reflection of the picture on the three-dimensional interpretation of the depicted object. Six pictures of a torso, taken from different vantage points, were reflected (i) about the horizontal axis and (ii) about the vertical axis. Participants performed local attitude settings by adjusting a thumb-tacklike figure so that it seemed to be painted onto the torso's surface. From these settings, the pictorial reliefs of all stimuli were constructed. Pairwise comparison between the pictorial reliefs of the original pictures and their mirror-image counterparts revealed differences that can be described by shears. Besides overall shears, piecewise differentiations occurred corresponding to different surface regions on the torso. This type of transformation is exactly what would be expected if observers change their mental viewpoint in an appropriate way.

- **Radial-frequency masking and the analysis of complex shape**

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Radial-frequency (RF) analysis provides a means of decomposing a common class of closed contours into component frequencies in a polar space. In the present study, we extend the analogy we have previously drawn (ARVO 2001) between RF space and spatial-frequency space. A two-alternative forced-choice paradigm was used to measure increment thresholds and cross-frequency masking for radial frequencies covering the 2–11 cycle range. Similar increment threshold functions were seen for 5 and 11 cycle RF patterns: a shallow dipper function was shown, and threshold elevations reached levels of 3–4 times threshold at a pedestal amplitude of 20× threshold. However, low RF patterns were subject to much less masking. We examined masking of both RF2 and RF11 patterns by a broad range of other frequencies. In all subjects, there was minimal masking of RF2 by any of the frequencies examined (RF3, RF5, RF11); in contrast, masking of RF11 patterns was strong at higher frequencies and decreased with decreasing mask RF. These results for high (RF11) and low (RF2) frequencies are compared with our previous results with an intermediate frequency (RF5) and are used to model the visual mechanisms supporting RF analysis.

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- **Discriminating moving angles**

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How does the visual system determine the shape of moving objects? We investigated angle discrimination for moving triangles defined by three dots (2 or 8 cycles deg⁻¹ D4's; D4 = fourth derivation of a Gaussian). Three base angles (30°, 60°, and 120°), three kinds of motion (translation, rotation, expansion), and a static control condition were tested. Speeds ranged from 180° s⁻¹ to 900° s⁻¹ (angular rotation) and 3.7 deg s⁻¹ to 12.2 deg s⁻¹ (translation and expansion). Presentation time was 400 ms. Discrimination thresholds were only marginally elevated relative to the static baseline for moderate speeds (180° s⁻¹), independently of the kind of motion, angular magnitude, and spatial frequency of the dots. Angular rotations of 600° s⁻¹ were required before performance deteriorated. Further increasing the rotational speed rendered the task impossible. Control conditions confirm that the high sensitivity for moderate speeds cannot be due solely to the visual system using one-frame (static) or two-frame (instantaneous speed estimate) snapshots, but instead requires an extended window of the motion.

In summary, angles can be discriminated equally well whether they are static or moving at moderate speeds. These results have strong implications for the cortical hardware and software involved in angle encoding. They strongly constrain models of separate (eg magnocellular and parvocellular) streams to have similar absolute angle-discrimination performance.

- **Squaring the circle: the cultural relativity of 'good' shape**

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The Gestalt theorists of the early twentieth century proposed a psychological primacy for circles, squares, and triangles over other shapes. They described them as 'good' shapes and the Gestalt premise has been widely accepted. Rosch (1973 *Cognitive Psychology* 4 328–350), for example,

suggested that shape categories formed around these 'natural' prototypes, irrespective of the paucity of shape terms in a language. Rosch found that speakers of a language lacking terms for any geometric shape nevertheless learnt paired associates to these 'good' shapes more easily than to asymmetric variants. We question these empirical data in the light of the accumulation of recent evidence in other perceptual domains that language affects categorisation. In a cross-cultural investigation we sought to replicate Rosch's findings with the Himba of Northern Namibia who also have no terms in their language for the supposedly basic shapes of circle, square, and triangle. In this replication, we found no advantage for these 'good' shapes in the organisation of categories. We conclude that there is no necessary salience for circles, squares, and triangles. Indeed, we argue for the opposite because these shapes are rare in nature. The general absence of straight lines and symmetry in the perceptual environment should rather make circles, squares, and triangles unusual and, therefore, less likely to be used as prototypes in categorisation tasks. We place shape as one of the types of perceptual input (in philosophical terms, 'vague') that is readily susceptible to effects of language variation.

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● **Effects of surface geometrical parameters on the visual perception of wrinkles**

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This paper deals with the relationship between the visual perception of the degree of wrinkles and the geometrical parameters of surfaces. Four potentially relevant parameters of the surface profile are considered: the variance, the cutting frequency, the effective disparity curvature (defined as the average disparity curvature of the wrinkled surface over the eyeball distance of the observer), and the frequency component of the disparity curvature. On the basis of experiments with garment seams having varying degrees of pucker (ie wrinkles along a seam line), we found that, while the logarithm of each of these four parameters has a strong linear relationship with the visually perceived degree of wrinkles, following the Weber–Fechner law, the effective disparity curvature and the frequency component of the disparity curvature appear to have stronger relationships with visual perception. This finding is in agreement with the suggestion by Rogers and Cagenello (1989 *Nature* **339** 135–137) that the human visual system may compute the disparity curvature in discriminating curved surfaces. It also suggests an objective method of measuring the degree of surface wrinkles.

● **Assessment of surgical outcome following repair of cleft lip and palate**

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The aim of this study was to evaluate the reliability and validity of clinical assessment, 3-D imaging, and 2-D imaging as methods of evaluating facial deformity in cases with repaired complete unilateral cleft lip and palate (UCLP). Thirty-one subjects with repaired UCLP were randomly selected; each case was assessed by two panels of assessors—a panel of five professional judges and a panel of five lay persons. The residual cleft-related facial deformity was assessed by direct clinical examination, projected 2-D images, and 3-D images. Each assessor scored the facial deformity of full face, lip, nose, and midface. Five-point scale was used for the assessment. The assessment procedure was repeated after one month. Weighted kappa score was used to assess agreements of scores across the three assessment media and also to evaluate inter- and intra-examiner reproducibility. We found that assessment of facial deformity was more reproducible with imaging systems than by clinical assessment. Inter-examiner reproducibility was significantly higher among professional judges than among lay assessors.

● **Decreasing suppression of target visibility by increasing the number of suppressors**

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A vernier masked immediately by a subsequent grating of 25 identical elements, centred at the location of the vernier, shines through this grating, ie has high visibility. If, however, the grating contains single odd-man-out elements, shine-through significantly deteriorates, as measured by the increasing offset threshold to discriminate the vernier offset direction. Target visibility is reduced, for example, when the two grating elements next to the central one are made longer. Thresholds increase more than threefold. Increasing the number of longer elements in a regular manner, surprisingly, recovers the performance and lowers the thresholds. If the grating contains alternate elements of longer and standard lengths, performance is as good as if all elements

have the standard length. Therefore, more suppressors lead to weaker suppression. It is the overall spatial layout of the grating that determines perception and performance. Though these results might favour processing mechanisms in higher visual areas, we suggest that the contextual influences via intra-cortical interactions in V1 are responsible. In particular, the recovered performance by additional, more peripheral, grating elements may be caused by the peripheral elements suppressing the more central suppressors, thereby disinhibiting the vernier. A V1 model is used to demonstrate our proposal.

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PERCEPTUAL LEARNING AND MEMORY

● Positional variation in perceptual learning: quadratic ideal observation, recurrent pre-processing, and transfer

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Residual eye movements introduce positional variation of stimuli on the retina in different trials of psychophysical experiments, a fact usually overlooked in models of perceptual learning. Using a bisection task as an example, we show that small positional variation changes the structure of the decision rule from linear to quadratic dependence on neural activities that code the input stimuli, invalidating linear feedforward models. We propose that a recurrent intra-cortical network, presumably in V1, that pre-processes the stimuli and is tuned through perceptual learning, is responsible for improved performance. Computer simulations in a network designed for a specific distance (2-D) between the outer bars in the bisection stimuli confirm this. However, such networks improve and impair performances for $D' \neq D$, implying positive and negative transfers of learning. Psychophysical tests, with bisection stimuli on an analog monitor controlled by a Macintosh, however, found only positive transfers, ie performance improvements, for $D' = D \pm D/2$, based on training at D . No transfer was found from line to dot bisection stimuli, so learning was indeed perceptual, and transfer cannot be attributed to a general improvement.

● Adaptation and consolidation in perceptual learning: sensory thresholds and evoked brain activity

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We studied the effects of training on peripheral vernier thresholds and evoked brain activity. Vernier thresholds were measured at the fovea, and in the left and right half-field (7.1 deg eccentricity) before, during, and after a training session of about 1 h duration as well as on the next day. During training, suprathreshold vernier stimuli were presented in one visual half field, and electric brain activity was recorded from thirty electrodes over the occipital brain areas. Evoked brain activity was compared between the first and the second half of training. Peripheral vernier thresholds were significantly larger than foveal ones. With training, thresholds in the trained half-field first increased but were significantly lower on the next day resulting in an overall improvement. Perceptual training also affected electrical brain activity that displayed smaller field strength and altered topography after training. Probably, adaptation or habituation to the training stimuli resulted in the initially impaired sensory performance associated with less efficient neurophysiological processing, and consolidation led to the final improvement. The topographical changes of the evoked components indicate that after training the responding neuronal populations are activated in a different way than before.

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● Specificity of statistical learning: the effect of contrast and figure – ground reversal

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Humans can efficiently extract higher-order statistics from visual scenes, including joint and conditional probabilities of shape co-occurrences. We investigated whether this statistical learning can generalise over contrast polarity and figure–ground reversal. Twelve different ambiguous

black-and-white images were used, organised into six base-pairs. Shapes of base-pairs were always displayed simultaneously and in an invariant spatial relation. During the learning phase, subjects passively viewed displays in which three base-pairs were pseudo-randomly arranged in a 3×3 grid. During the test phase, subjects compared base-pairs to non-base-pairs, where non-base-pairs were composed from two elements never appearing together during the learning phase. Pairs in different trials were shown either in their original format, or with their contrast reversed, or with a reversed local background changing the figure-ground assignment of the images. Observers selected the original base-pairs as the more familiar pattern significantly more often than the corresponding non-base-pairs. However, they were at chance in selecting base-pairs over non-base-pairs in the other two conditions. These results imply that learning of higher-order statistics from visual scenes does not generalise over contrast and figure-ground reversal and thus exhibits a surprisingly high specificity for the identity of shapes constituting the scene. [Supported by the Hungarian National Research and Development Program (2/035).]

● **Activity and familiarity of memory contents influence spatial attention**

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Working memory is closely related to attention. Attention controls what sensory information is allowed into working memory, and the contents of working memory influence the allocation of selective attention (Downing, 2000 *Psychological Science* **11** 467–473). This interaction may not always occur, however. For instance, if the information held in working memory is not active enough, it may not be able to guide attention. Then, when and how does working memory guide attention? On the assumption that novel stimuli held in working memory should be more activated than familiar stimuli, we examined whether the familiarity of stimuli in working memory affects the allocation of attention. Familiarity of information was manipulated by presenting the same novel stimuli repeatedly. When subjects had to remember novel objects, they showed faster probe RTs at the locations that the novel objects had occupied. On the other hand, however, as the object was repeated and became familiar, the content of working memory no longer had influence on allocating attention. These results suggest that human brain processes novel objects and familiar objects in different ways and that the activation of memory contents is critical for guiding spatial attention. Other properties of working memory that may influence attentional allocation are discussed.

● **Blindness for items retained in working memory**

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It has been shown that the focus of visuospatial selective attention is driven by the contents of visuospatial working memory (Awh and Jonides, 2001 *Trends in Cognitive Sciences* **5** 119–126). In the present study, we used an attentional blink task to investigate whether such enhanced attention for the contents of working memory (WM) also occurs for objects (letters). Participants were to identify two letter targets (T1 and T2) presented by rapid serial visual presentation, while retaining 0 or 3 letters in WM. On half of the trials in which a memory load was present, T2 was a member of the memory set. A typical attentional blink was found regardless of WM load. However, contrary to the expected enhancement of attention for items retained in WM, T2 was identified less often when it was part of the WM set than when it was not. The magnitude of this negative repetition (NR) effect was stable across lags. A second experiment showed that the NR effect occurs even when T2 is presented in uppercase and the WM set is presented in lowercase.

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● **Depth differences modulate object formation for visual working memory**

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Recent research indicates that the operational units of visual working memory (VWM) are whole objects rather than features or, more generally, the total amount of information to be remembered. An attempt is made here to characterise the object formation process for VWM, by asking whether the object formation process precedes or follows a stage of surface assignment. Observers memorised the colour of four objects with two parts for 300 ms, followed by a mask. A post-cue then indicated which of the four objects' colour was to be reported. The experiment was designed to manipulate whether there were any depth differences between the parts of each object.

Apparent depth differences (interposition), as well as 'real' depth differences (disparity induced) between the parts of the objects to be memorised interfered with memorisation when both parts of the objects needed to be remembered, while depth differences aided performance when only one feature was to be remembered. The results showed that real and apparent depth differences interfere with the object formation process, suggesting that object formation for visual short-term memory follows a stage of surface assignment.

● **Estimation of component ratio in a brief presentation**

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The ability to estimate the component ratios of a briefly presented stimulus was examined. The stimulus consisted of small red and green circles, which were randomly arranged in a 20×20 matrix. The ratio of one component was varied systematically from 10% to 90% in 10% steps. In a preliminary experiment, the baseline of ratio estimates under a given duration of stimulus without a mask was measured. The observers could make precise estimates of the component ratio for almost all presented ratios. In a subsequent experiment, the effectiveness of early visual information in the ratio judgments was tested with the use of a masking technique. Three SOAs—17.7 ms, 35.4 ms, and 195.0 ms—were used. The results were compared with the baseline. Ratio estimates in the 17.7 ms and 35.4 ms conditions showed relatively larger SDs and their means were approximately 50% for lower and higher ratios presented. This implies observers were unable to estimate these ratios. Ratios in the 195.0 ms condition were overestimated overall and their SDs were relatively small. Observers, however, could make rough estimates of almost all ratios in this condition. These results suggest that early visual information, corresponding to visual iconic memory, is available when making ratio estimates.

● **Perceptual learning of visual letter recognition**

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Training effects can be observed for a lot of perceptual processes. The question at issue was whether lateral masking effects (ie the reduction of target recognition performance when presenting flanking letters on each side of the target), which are assumed to be the sensory basis of visual letter and word recognition, can be reduced by training, and, if so, which processes are facilitated by training. In experiment 1, there were no training effects on recognition performance for target letters presented with randomly selected flanking letters. In experiment 2 with fixed flankers, performance improved when participants performed a whole report task with the same stimuli before. In experiment 3, effects of feedback on training were assessed. A significant improvement of recognition performance relative to controls was observed only for trained strings when feedback provided information about the flankers. Under certain conditions, lateral masking effects can be reduced by training. The missing transfer to other than learned stimuli shows that the improvement is not due to enhanced target selection. The results indicate that the stimuli are learned, but only if the feedback contains information about the flanking letters. This suggests that a certain orienting of attention is a prerequisite for learning.

WEDNESDAY
ORAL PRESENTATIONS**ATTENTION**

◆ **Attention enhances spatial resolution by shifting sensitivity to high spatial frequencies: evidence from selective adaptation and masking paradigms**

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In a texture-segmentation task in which performance peaks at mid-periphery and drops at both central and peripheral locations, attention improves performance at peripheral locations but hinders performance at central locations. This indicates that attending to the target location improves performance where the resolution is too low (periphery) but impairs it where resolution is already too high (central locations) for the task (Yeshurun and Carrasco, 1998 *Nature* **396** 72–75; Yeshurun and Carrasco, 2000 *Nature Neuroscience* **3** 622–627).

To explore whether attention enhances spatial resolution by increasing sensitivity to high spatial frequencies, we employed the selective adaptation and backward band-masking paradigms, while manipulating transient covert attention by precueing the target location. In one experiment, observers adapted either to a high-spatial-frequency or a low-spatial-frequency sinusoidal grating. In another, the display was followed either by a high-pass or a low-pass mask.

Either selective adaptation to high spatial frequencies or the presence of a high-pass mask diminished the central performance drop and eliminated the attentional impairment. In contrast, the presence of a low-pass mask augmented the central performance drop in the precue condition. These experiments confirm the spatial nature of the central performance drop and, more importantly, they indicate that attention enhances spatial resolution by shifting sensitivity to higher spatial frequencies.

◆ **Attentional modulation of target – flanker lateral interactions: effects of manipulating attention to spatial and non-spatial flanker attributes**

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We recently demonstrated that lateral interactions between a central target and collinear flanking Gabors can be modulated by attention to the flankers (2001 *Nature Neuroscience* **4** 1032–1036). In those studies we manipulated attention by requiring subjects to perform a secondary Vernier alignment task on one of two pairs of flankers (arranged in an ‘X’ configuration) while ignoring the second flanker-pair. Flankers facilitated detection of collinear central targets only when they were task-relevant. Here we ask whether the attentional modulation depends on the nature of the secondary task applied to the flankers. Two new 2AFC flanker tasks were introduced (in addition to the original Vernier task): judging the global orientation of a flanker-pair, and detecting differences in contrast between the two relevant flankers. The Vernier and global-orientation tasks (involving judging spatial relationships between the flankers) tended to produce greater modulation than the flanker contrast-discrimination task (requiring attention to non-spatial attributes). Differences between these conditions may indicate that attentional modulation of flanker interactions is contingent on the specific type of perceptual analysis required by the flanker task. [Funded by BBSRC.]

◆ **On defining the condition of stimulus-driven attentional capture**

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We examined the conditions under which stimulus-driven attentional capture is possible. A letter discrimination task was used in which the participants responded differentially to one of the two possible target letters (H or U) among multiple irrelevant letters. A distractor was shown before the target display to see whether the distractor affected the response to the target. In eight experiments, we manipulated the ways the distractor (colour or onset) and the target (non-onset or onset, with or without defining features) were presented, as well as their SOA and set size. Our results showed that increasing the set size increased the chance of capture by salient stimuli, especially at 150 ms, 200 ms, and 250 ms SOAs, and the absence or presence of a defining feature for the target seemed to affect only the small-set-size conditions. Sharing common features with the target (eg red distractor and red target) did not guarantee attentional capture by the distractor in the small-set-size conditions, unless it accompanied changes in the feature dimension between the distractor and the target displays. These results clarified the notion of

displaywide attentional capture and helped in solving the discrepancy between stimulus-driven and contingent attentional capture.

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◆ **Sleep deprivation as an instrument for the analysis of attention**

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I propose that sleep deprivation and related techniques are valuable tools for investigating visual attention. I present data from three studies of different aspects of visual attention: visual search, spatial cuing, and attentional blink (AB) during one such protocol (constant routine). The protocol featured 36–40 h of continuous wakefulness with no time cues, a semirecumbent posture, and dim lighting. In the visual-search study, reaction time (RT) was measured in a standard spatial configuration search for 5s among 2s. Perception/decision time (RT—set size intercept) increased by 400 ms with sleep deprivation, but search time per item (slope) did not change significantly. In the spatial cuing study, in a standard Posner cuing task, overall RTs showed little effect of sleep deprivation. However, RT on invalid trials increased substantially, indicating sleepy subjects had difficulty disengaging attention. In the attentional blink study, subjects reported digits in an RSVP letter stream. AB was observed with two digits in the stream. Sleepy subjects showed attenuated AB and decreased overall accuracy. The three tasks do not show a uniform response to sleep deprivation. By comparing the effects of sleep deprivation on different tasks, we can learn about the relationship between different attentional mechanisms, and speculate about their potential neural substrates.

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◆ **Separate attentional resources for discrimination of colour and luminance**

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Paying attention can improve vision in many ways, including some very basic functions, such as contrast discrimination, a task that probably reflects very early levels of visual processing. An interference paradigm was employed, where subjects were required to perform two tasks concurrently: a primary task, discriminating which of the two 1 cycle deg⁻¹ gratings displayed at 6 deg eccentricity had higher contrast, and a secondary task where subjects were required to report whether the 20 central disks (18 min of arc diameter) had all the same contrast, or not. The stimuli for both tasks could be modulated either in luminance or in red–green equiluminous contrast. Performing the central task with luminance stimuli increased significantly increment thresholds over the mid-contrast to high-contrast range, leaving absolute threshold unaffected. However, when the central task required a chromatic discrimination, it had no effect at all on the luminance increment thresholds. Similarly, increment thresholds for chromatic contrast deteriorate when the observer is currently performing another colour discrimination task, but not when he or she is performing a luminance discrimination task. Modelling suggests that attention improves contrast discrimination by increasing multiplicatively the gain of the neuronal response to contrast. The effects of attention are highly modality-specific, implying separate attentional resources for colour and luminance contrast at early stages of visual processing.

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LOCAL MOTION

◆ **Directional tuning of lateral interactions**

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Detection of contour structure is promoted by the presence of consistent local motion signals, and local directional signals organised into consistent motion trajectories are highly salient visual features. We employed a contrast-facilitation paradigm (Polat and Sagi, 1993 *Vision Research* **33** 993–999) to examine the underlying connectivity supporting such phenomena. Specifically, we measured contrast sensitivity for a horizontal Gabor (12 cycles deg⁻¹, 5 min SD), drifting at 4 Hz, flanked either horizontally or vertically by two identical Gabors of 50% Michelson contrast. The separation between target and flanks was varied systematically. Small separations ($\lambda - 2\lambda$) produced masking, larger separations (up to 24λ) produced facilitation of target detection, irrespective of the orientation configuration. Opposite direction flanks and counterphase flickering flanks (the sum of two identical Gabors drifting in opposite directions) only masked

detection and this effect decreased with separation. We also varied the speed of flanks positioned at 3λ , and found that facilitatory interactions were bandpass-tuned for speed. Thus lateral interactions for moving stimuli extend over distances up to eight times greater than for static stimuli and include flanks positioned perpendicular as well as parallel to the contour. This is consistent with the integration of trajectory and contour information.

◆ **Vertical motion looks faster than horizontal motion**

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We investigated the effect of direction of motion on speed perception. Subjects speed matched drifting, sinusoidal modulations of luminance, windowed by a stationary Gaussian, in a temporal two-alternative forced-choice paradigm. The standard stimulus was a 1 cycle deg^{-1} grating, drifting at 1 deg s^{-1} . In any one session, all possible comparisons were made between up, down (vertical axes of motion), left, and right (horizontal axes of motion). Speed matching was accurate when comparing within axis of motion (ie horizontal with horizontal, or vertical with vertical), but both upwards and downwards moving gratings were seen as moving more rapidly than either leftwards or rightwards drift. The lack of any difference in speed estimates of gratings drifting upwards and downwards (ie within the vertical axis of motion) appears to rule out a gravitational explanation of the mismatch across axes of motion. An alternative hypothesis is that subjects characterise speed as distance over time (or use ratios of spatial and temporal derivatives to extract velocity); if this were the case, the faster apparent speeds noted for vertically moving gratings could be explained if visual space were perceptually expanded in the vertical direction (as, for example, in the horizontal-vertical illusion).

◆ **Separating energy-based and feature-based accounts of motion discrimination in random-dot kinematograms**

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Direction discrimination performance in random-dot kinematograms (RDKs) can be modelled successfully with either spatiotemporal energy-based or feature-based models, and the output of these two model types is often highly correlated. We report here three experiments that sought to distinguish between them. First, we randomised the spatial phase of standard RDKs. The energy model predicts that phase randomisation should have no effect on performance, as it does not affect the shape of the spatial-energy envelope. The feature model predicts a deficit in performance, due to an increase in the number of features (eg zero crossings) in the phase-randomised pattern. We found very similar performance for phase-randomised RDKs, compared to un-randomised controls, in line with the energy prediction. Second, we compared performance using RDKs with similar feature statistics but with either normal (flat) or $1/f$ energy profiles. The feature model predicts no difference in performance. The energy model predicts better performance with the $1/f$ stimulus. Data showed much better performance in $1/f$ RDKs, in line with the energy prediction. However, in a third experiment in which we manipulated density in phase-randomised patterns we found improved performance at lower densities. There is no straightforward account of density effects in the energy model.

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◆ **Masking effects between local first-order and second-order motions in the extraction of global-motion direction depend critically on stimulus visibility**

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The presence of second-order (SO) motion 'noise' dots does not change the number of first-order (FO) 'signal' dots needed to identify global-motion direction. This has been taken as evidence that FO and SO motions are processed independently up to and including the stage of global-motion analysis (eg Edwards and Badcock, 1995 *Vision Research* **35** 2589–2602). However, FO noise dots have been shown to markedly elevate global SO-motion thresholds, casting doubt on this assertion. As similar asymmetric masking effects occur between FO noise and FO signal dots of unequal contrast, it is possible that a common global-motion mechanism can integrate both FO and SO local motions, but only when their effective modulation depths (visibilities) are comparable. To test this possibility, we measured global-motion thresholds for FO (luminance) signal dots in the presence of SO (contrast) noise dots and vice versa. When the visibility of SO noise dots was low relative to FO signal dots, thresholds were unaffected, but doubled as the

contrast of FO dots decreased. Low-contrast FO noise dots also had little influence on thresholds for more visible SO signal dots. Thus the relative visibility of local FO and SO motions determines whether or not they interact to influence perceived global direction.

◆ **Apparent standstill of rapidly moving first-order and second-order motion stimuli**

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Motion standstill is a phenomenon in which the pattern, colour, texture, and/or depth of a rapidly moving stimulus can be perceived, but the stimulus appears to be standing still; that is, all motion systems fail while other systems are still functioning. Motion standstill has been produced reliably in third-order motion displays: in stereo motion at temporal frequencies of 5–7 Hz (Julesz and Payne, 1968 *Vision Research* **8** 433–444; Tseng et al, 2001 *Investigative Ophthalmology & Visual Science* **42** Supplement, 2720) and in motion of red–green gratings by making red and green stripes equally salient as well as equiluminous (Lu et al, 1999 *Proceedings of the National Academy of Sciences of the USA* **96** 15374–15379). To demonstrate motion standstill in the first-order and second-order motion systems, we used moving luminance and moving contrast-modulated-texture sine gratings. They were presented either centrally or peripherally, with various spatial and temporal frequencies (f_x , f_t), slanted either $+45^\circ$ or -45° , moving either up or down (90 deg per frame). Centrally viewed gratings were circular discs whose edges were smoothly windowed to remove terminators' effect on motion judgments; peripheral gratings were circular annuli, similarly windowed. For each observer, with both first-order and second-order stimuli, and for both central and peripheral viewing, we found combinations of f_x and f_t that lead to perceived motion-standstill.

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VISUAL SEARCH

◆ **Colour grouping removes an attentional bias to central stimuli**

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Search efficiency falls off with increasing target eccentricity only when distractors occur closer to fixation than the target (Wolfe et al, 1998 *Perception & Psychophysics* **60** 140–156). This suggests that the effect of eccentricity originates from a spatial bias to attend to central items. We found evidence for such a bias using an odd-man-out variant of conjunction search. However, the bias was overridden in conjunction search for a predefined target. Distractors were always of two types, white horizontal and black vertical lines, segregated from each other in central and peripheral regions of a radial display. In (colour)-odd-man-out search, a target was either a black horizontal line (amongst white horizontal distractors), or a white vertical line (amongst black vertical distractors). In conjunction search, the target was always a white vertical line. With increasing target eccentricity, detection times for a white vertical target increased for the odd-man-out, but not for the conjunction-search, task. We suggest that in conjunction search top–down knowledge of target colour encouraged across-eccentricity colour grouping between a target and same-colour distractors, and that attention was allocated evenly across the resulting group. Thus top–down-induced grouping removes a spatial attentional bias.

[Supported by Medical Research Council, UK.]

◆ **The eyes can search large displays more effectively than small ones: an oculomotor paradox?**

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We report a set of results showing that increasing the number of distracting elements in a visual-search task improves oculomotor search performance. A search target was presented together with distractors and subjects were required to move their eyes to the target. When the target was presented with a single distractor in a neighbouring location, the first saccade was often inaccurate. However, increasing the number of distracting elements from 1 to 15 considerably improved the ability to locate the target with the first saccade. We considered two hypotheses to account for this paradoxical finding. Perceptual grouping processes might operate amongst the distractors. However, when we modulated the heterogeneity of distractors in the displays with 15 distractors on four dimensions separately, performance did not deteriorate. The second hypothesis arose from the observation that the first saccades in large displays generally showed longer latency. When we introduced distractors contralateral to the target, this induced a 'remote distractor effect' whereby saccade latency increased. Search performance was superior in this condition to that when all distractors were ipsilateral. We suggest that oculomotor search performance

is improved with greater distractor number because contralateral onsets increase initial saccade latency and in consequence allow improved perceptual selection.

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◆ **Saccadic search: the relation between fixation duration and saccade amplitude**

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In most large search displays a number of fixations is required to find a target. The size of the area that can be inspected during a single fixation increases with time (Geisler and Chou, 1995 *Psychological Review* **102** 356–378), indicating that fixation time and saccade amplitude should correlate. This suggests that observers may adopt various search strategies (eg short fixation times and small saccade amplitudes or long-lasting fixations and large saccades). It is also known that visual processing time increases with search-task difficulty. Thus when task difficulty is varied, subjects may adjust fixation time, saccade amplitude, or both. However, how do subjects adjust saccade amplitude and fixation time to the demands of a search task? Subjects were instructed to find one circle (the target) among many Cs in a large stimulus (40 deg × 30 deg). In 12 sessions we varied the number of elements (36, 64, 100, or 144) and gap size in the C (0.095, 0.19, or 0.38 deg; element size is 0.76 deg). Search strategies of all subjects were similar. Fixation time decreased and saccade amplitude increased with increasing gap size and increasing element distance. Of all hypothetical search strategies, fixation time increased with decreasing saccade amplitude irrespective of task difficulty.

◆ **‘Attention deceived’: ERP correlates of covert attention shifts during change blindness**

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The detection of salient changes in an image is delayed if the original and modified version are presented in alternation and separated by a screen flicker. To examine whether event-related brain potentials (ERPs) preceding the overt change detection reflect the comparison of single elements or implicit storage of the layout of the image, we compared the effect of a recurrent displacement of one element in a 6 deg × 6 deg array of ten alphanumeric symbols with that of a more complex design involving two displacements. In the standard condition 60 original images (O) were presented in alternation with modified images (O–M–O). In the new condition, three displacements (image M1: element 1; image M2: element 2; image M3: both elements) were interleaved between two presentations of O (O–M1–M3–M2–O). Subjects’ ($n = 10$) overt detection was significantly delayed in the more complex design (6.5 versus 5.4 s). In both experimental conditions but not in the control (O–O), a frontocentral ERP positivity occurred as early as two images before detection. It was significantly increased one image before detection in the standard, but interrupted by a frontal negativity in the new condition. This ‘veto’ signal suggests that covert processing of changes is based on single elements rather than the layout of the image.

◆ **A performance model for visual search**

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We discuss a signal-detection-based model with fixed internal noise and varied external noise which increases with the number, m , of noise elements in a stimulus array. If information is accumulated over time, such that a longer reaction time indicates more complete information about the stimulus, then a useful measure of performance, which combines both speed and accuracy, is performance in units of $d'^2 \text{ s}^{-1}$. We apply this simple metric to data from visual-search experiments and show that ‘efficient’ performance, as defined in terms of RT alone, may sometimes be inefficient by this criterion. We also show that this metric behaves appropriately when signal contrast or set size are varied. Finally, we relate this metric to the drift rate in a random walk; it is proportional over a fair range of drift rates.

GLOBAL MOTION

◆ **Dynamics of pattern motion signals in macaque area MT**

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Neurons in area MT of the macaque are selective for the direction of motion. Responses to gratings and plaids classify MT neurons as pattern-direction selective (PDS) or component-direction

selective (CDS), indicating whether they are selective for the motion of patterns or of their oriented components. We have explored the time course of the computations underlying these responses by comparing the latency and dynamics of selective responses in CDS and PDS neurons in opiate-anesthetised macaques, using a continuous rapid pseudo-random sequence of gratings and plaids moving in different directions.

On average, CDS neurons have response latencies 10 ms shorter than PDS neurons. Furthermore, CDS neurons convey a reliable component-motion signal roughly 40 ms earlier than PDS neurons convey a pattern-motion signal. The first 10–20 ms of the response of some PDS neurons appears to be CDS-like, but CDS neurons never appear PDS-like.

The nature of motion response of the MT population evolves after motion onset. The earliest response signals component motion, and only later does a reliable pattern-motion response emerge. These results suggest that PDS involves more neural computation than CDS, and may also account for the previously reported transition from component-dominated to pattern-dominated percepts in the period immediately after motion onset.

◆ **Direction repulsion effect occurs at the global-motion level**

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Apparent angular difference in motion directions of two superimposed sets of dots is exaggerated when actual direction difference is less than approximately 135° ; a phenomenon known as direction repulsion. Direction repulsion and stimulus speed are inversely related across a range of speeds. The level of motion processing at which direction repulsion occurs—local or global—is the subject of ongoing debate, and can differentiate between computational approaches to the phenomenon. Observers were presented with random-dot kinematograms containing two superimposed motions, whose global-motion directions differed by 50° – 110° . Motion directions were judged by adjusting the orientation of two radial lines. Dots from one set moved in the same direction; dots from the second set took a 'random walk', with each dot direction randomly chosen from a predetermined direction distribution width for each image frame. As direction distribution width increases, perceived global speed decreases; but, critically, local dot speed is unaffected. If direction repulsion occurs globally, increasing direction distribution width will result in increased repulsion magnitude. If it occurs locally, repulsion magnitude will be unaffected. Our current results show that repulsion magnitude increases with increasing direction distribution width, suggesting that direction repulsion occurs at the global-motion level.

◆ **Perpendicular component motion can continually dominate the motion of intrinsic contour terminators**

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The motion perceived in a field of moving bars is initially perpendicular to the orientation of the bars, rotating to the actual direction of motion within about 200 ms (Lorenceau et al, 1993 *Vision Research* 33 1207–1217). Beyond this initial integration period, however, the motions of the intrinsic terminators belonging to the moving bars largely determine the perceived direction of bar motion (Wallach, 1935 *Psychologische Forschung* 20 325–380; Lorenceau and Shiffrar, 1992 *Vision Research* 32 263–273). Reliance on the unambiguous motion of contour discontinuities contributes to the solution of the aperture problem. Here, we demonstrate the existence of a new class of motion stimuli where the component of motion that is perpendicular to a moving contour dominates perceived motion, even when there is no aperture, and intrinsic terminators are entirely visible and moving in a different direction. Far from dissipating within 200 ms, the perpendicular component of bar motion dominates perception continually. If several such bar stimuli are placed in two different orientations with respect to their common actual motion, they appear to break into two sets, each moving along its respective perpendicular component. Thus, grouping can take place on the basis of an entirely illusory common motion. Optimal conditions and possible explanations for this stimulus class are discussed.

◆ **'Speedlines' aid perception of motion direction**

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Geisler (1999 *Nature* 400 65–69) proposed that streaks left in the wake of a moving object may be detected by orientationally selective mechanisms (with appropriate temporal integration) and used to help disambiguate motion direction. Here we test this idea directly by measuring thresholds for discriminating the direction of motion of a field of moving dots superimposed on

orientationally filtered noise, oriented either parallel or orthogonal to the dot motion. Orthogonal noise had little effect on direction discrimination thresholds, while parallel noise raised them by a factor of about 8. The detrimental effect decreased with increasing orientation-bandwidth for the parallel noise, and increased with bandwidth for the orthogonal noise. Parallel noise specifically impeded motion direction discrimination, having virtually no effect on either contrast thresholds or speed discrimination. We also measured direction discrimination thresholds for random fields of dot pairs that were oriented either coherently to form Glass patterns or at random. Motion direction thresholds were considerably higher when the dot pairs were oriented coherently and near the direction of motion than when they were oriented randomly. Similar results were obtained for motion along a spiral trajectory. The results provide direct evidence that motion traces, effectively 'speedlines', give information about motion direction that is used by the visual system. The presence of oriented masks, either in the form of orientation-filtered noise or coherent Glass patterns confounds this information source, either by reducing sensitivity to the motion traces or by producing false traces that mislead motion mechanisms.

◆ **Contrast can affect the perceived direction of motion, and of motion aftereffects**

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(i) A gray diamond centred in a four-quadrant surround made small vertical jiggles. The top-left and bottom-right edges of the diamond lay on dark quadrants while the other two edges lay on light quadrants. When the diamond was light-gray, its top-left and bottom-right edges had high contrast and its perceived motion was left-oblique. A dark-gray diamond appeared to move right-obliquely. Nulling measurements showed that the motion ratio of the two edges was a power function of their contrast ratio, with an exponent between 0.5 and 1.5.

(ii) Sparse, black random dots drifting to the right were superimposed on sparse white dots drifting downwards. These were seen as separate and transparent. However, the resulting aftereffect was in a single oblique (up-left) direction. The surround luminance was varied. A light-gray surround increased the contrast of the black rightward-moving dots relative to the white downward-moving dots and biased the MAE toward the left. Correspondingly, a dark-gray surround biased the MAE upward. The linear relationship between the logarithm of relative contrast and MAE direction indicated adaptation to a contrast-weighted vector summation of the two motions.

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SYMPOSIA

PLYMOUTH SYMPOSIUM ON VISUAL AWARENESS: IS SEEING KNOWING?

▶ **Conscious experience and perception without awareness**

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How does visual information perceived without awareness influence conscious experience? Before this question can be answered, it is necessary to have an adequate measure of whether an experimental participant (either human or non-human) is aware of a visual stimulus. Studies of visual awareness in humans have used two general types of measures: objective measures based on forced-choice discriminations, and subjective measures based on verbalisations of conscious experiences. Both types of measures have strengths and weaknesses. However, when all things are considered, subjective measures provide a more direct and a more accurate indication of both the presence and absence of awareness than can be provided by any objective measure of awareness. In fact, an objective measure can only provide a reliable indication of the presence of awareness if it is validated by a subjective measure. When subjective measures are used to distinguish perception with awareness from perception without awareness, it has been found that visual stimuli perceived without awareness can influence conscious experience in two distinct ways. First, visual stimuli perceived without awareness can bias what stimuli are attended and therefore perceived with awareness. Second, visual stimuli perceived without awareness influence how attended stimuli are consciously experienced. Thus, two important functions of perception without awareness are that it biases what is perceived with awareness and influences how stimuli are consciously experienced.

► **Responses of single neurons in the human medial temporal lobe during visual stimulation, imagery, and flash suppression**

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One popular approach to visual awareness is to record the activity of single neurons while manipulating the subject's percept. In collaboration with Dr Itzhak Fried at UCLA Medical School, Gabriel Kreiman from our laboratory is recording spiking activity in the medial temporal lobe of patients with intractable epilepsy. On the basis of clinical criteria, intracranial electrodes were implanted to localise seizure foci for surgical resection. We recorded single-unit activity while patients viewed pictures, were asked to imagine these with closed eyes and during flash suppression. Recording from more than 1000 units in conscious humans we found that (i) individual neurons respond very selectively to visual stimuli from different natural categories, including faces; (ii) a subset of these cells have the identical selectivity during imagery; and (iii) the majority of the visually selective cells follow the percept during flash suppression, while none of these neurons is active for a perceptually suppressed stimulus. These results help to explain psychophysical findings (Li et al, 2001 ARVO) that animals or faces can be detected in natural scenes in the (near)-absence of visual attention.

► **The prefrontal cortex and cognitive control**

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What controls your thoughts? How do you decide what to pay attention to? How do you know how to act while dining in a restaurant? How do you plan your day or even a simple errand? This is cognitive control, the mechanisms by which your brain wrests control of its processes from reflexive reactions to the environment in order to direct it toward future aims. It has long been thought to depend on the prefrontal cortex (PFC), a brain region associated with thoughtful, intelligent behaviour—the ability to ignore distractions, keep 'on task', and control impulses. Results from our laboratory have shown that PFC neurons have complex properties commensurate with a role in 'executive' brain function. They are involved in directing attention, in recalling stored memories, and they integrate the diverse information needed for a given goal. Perhaps most importantly, they transmit acquired knowledge. Their activity reflects learned task contingencies, concepts, and rules. In short, they seem to underlie our internal representations of the 'rules of the game'. This may provide the necessary foundation for the complex behaviour of primates, in whom this structure is most elaborate.

► **Visual awareness and the dorsal attention system**

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Visual awareness (what we see and remember) is controlled by both sensory and behavioural factors. The sensory salience of objects (brightness, hue, contrast), and their behavioural relevance (how they match ongoing goals or expectations) influence where, how, and to what we pay attention in the visual environment. Brain-imaging studies show that a dorsal system, which includes frontal eye field (FEF) and regions along intraparietal sulcus (IPs), is recruited when we attend to a visual attribute (like the location or direction of motion of a stimulus). This system is also recruited during the preparation of responses like an eye movement or an arm movement. Hence, this network is involved in the generation and maintenance of expectations/goals (top-down control). The dorsal network is also modulated by sensory salience. As we search and detect a target in the environment, activity in this network increases during search, and is further modulated at the time of detection. Therefore, this network combines top-down and bottom-up information during search/detection of targets. Concurrently, the visual cortex shows increases with search, and modulation by target detection. Finally, target detection produces widespread modulations in large parts of the cortex. These findings suggest that: (a) visual awareness (as indexed by the moment in which a target is detected) may depend on an interaction between a dorsal control network (FEF-IPs), and visual areas; (b) visual awareness may be a state that is broadly broadcast throughout the brain.

► **Can patients with blindsight discriminate images of objects?**

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Blindsight is the ability of patients with visual field defects from retrogeniculate lesions to respond nonreflexively to stimuli they can no longer consciously see. Among the various functions that have been demonstrated, form and object discrimination have been particularly difficult to demonstrate, which tied in neatly with physiological findings of residual visual responsivity in dorsal, but not ventral, stream cortical visual areas. Nevertheless, our investigations of residual processing of images of objects in which we used 2AFC as well as priming paradigms, show (a) that patients were faster in categorising drawings of objects presented in their normal field when an identical one in the blind field preceded their presentation; (b) that a priming effect was also present when the prime was not identical but semantically related to the target; (c) that patients were able to learn to discriminate coloured images of natural objects; and (d) that this ability could extend to discriminating between an object shown in an original and a scrambled version of itself. As our fMRI data revealed BOLD responses in ipsilesional ventral cortical areas to images of objects in the blind field, we suggest that these high-level residual functions involve ventral processing whose strength may depend on the extent to which the patients have learned to use their blind field. Blindsight is not an all-or-nothing phenomenon but an ability that develops through training.

REVERSE CORRELATION

► **Psychophysical reverse correlation as a potential bridge between perception and physiology**

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This talk describes experiments that show how psychophysical reverse correlation may provide useful information as to the physiology underlying perceptual processing. The emphasis is on the idea that this technique is maximally informative when: (i) the sensory filters returned by reverse correlation show features that are not already present in the signal; and (ii) these features are interpretable in the context of what we know about the physiology of visual cortex. Examples span stereo-surface detection, luminance-defined feature detection, and colour-defined feature detection.

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► **Using response classification to examine the face-inversion effect**

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Face recognition is more difficult when faces are inverted by 180°, an effect that often is attributed to a qualitative shift from configural processing of upright faces to featural processing of inverted faces. We examined this idea using Ahumada's response classification technique to measure the parts of a face that are used for recognition. Five observers judged which of two faces was presented on each trial. The faces were embedded in white Gaussian noise, and stimulus contrast was varied to maintain 71% correct responding. Noise fields were sorted and combined to yield an estimate of each observer's linear face-recognition template. Finally, classification images were used to predict each observer's absolute efficiency. Absolute efficiency was significantly higher for upright than for inverted faces, and observed efficiencies in both conditions were slightly higher than the predictions. We show that these results suggest that nonlinear mechanisms contributed to performance, but that their effects were similar for upright and inverted faces. Therefore, the inversion effect was due entirely to changes in the sampling efficiency of linear recognition mechanisms. Our results suggest that the face-inversion effect, at least in our conditions, reflects a quantitative, rather than a qualitative, change in processing.

► **Superstitious perceptions**

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We have all seen a human face in a cloud, a pebble, or in blots on a wall. Evidence of such 'superstitious' perceptions have been documented since classical antiquity [Gombrich, 1960 *Art and Illusion* (London: Phaidon); Janson, 1973, in *Dictionary of the History of Ideas* Ed. P P Wiener (New York: Charles Scribner's Sons)] but have received little scientific attention. We have recently studied superstitious perceptions in our laboratory. In one experiment (Gosselin and Schyns *Psychological Science* in press, experiment 1), for example, we presented 20 000 white-noise fields

to three observers who believed they were participating in a regular 'S'-letter detection task. The observers were never shown the target 'S' letter but were given some information about it: they were told that it filled the screen and was black on a white background. All observers detected such an 'S' letter in an important proportion of the trials. Using reverse correlation [Wiener, 1958 *Nonlinear Problems in Random Theory* (New York: John Wiley); Ahumada and Lovell, 1971 *Journal of the Acoustical Society of America* **49** 1751–1756], we extracted the first and second Wiener kernels subtending these detections. The first Wiener kernels were similar to an 'S'. Moreover, they possessed spectral properties compatible with those reported in the psychophysical literature (Solomon and Pelli, 1994 *Nature* **369** 395–397). The second Wiener kernels all had pixels reaching significance levels (this is a little surprising given the fact that the instructions given to the observers were biased toward linearity). We discuss the results of other superstitious-perception experiments on letters and faces (Gosselin and Schyns *Psychological Science* in press), and surface representations (Gosselin et al, submitted).

► **Maximum-likelihood analysis of individual responses to stochastic stimuli**

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Models of visual function are typically fit to statistics of performance. For example, I once reported estimates of channel bandwidth based upon thresholds for detecting targets in filtered noise. However, because statistics inherently discard data, I now advocate fitting models to every individual response whenever stochastic stimuli are used. The very existence of this symposium attests to the value of analysing individual responses. However, even amongst practitioners of reverse correlation, data distillation prior to model fitting is the norm. To cite an example, Abbey and Eckstein (2002 *Journal of Vision* **2** 66–78) summarised the results of 2000 trials in a single radially symmetric classification image, then showed that this image was significantly different from what an ideal observer would produce. One advantage of Abbey and Eckstein's analysis over the one I advocate, namely fitting a model to the joint likelihood of all responses, is that theirs makes no assumptions with regard to the distribution of equivalent noise. However, had they made the conventional assumption of Gaussian equivalent noise and had observers used a slightly narrower than ideal template, then the same level of confidence ($p < 0.01$)—that observers did not use the ideal template—could have been reached in a mere 500 trials. Moreover, the maximum-likelihood approach can be used to test hypotheses about any parameters within a model, not just those related to template shape.

► **Planning classification image experiments**

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Recent papers on the estimation of classification images (Ahumada, 2002 *Journal of Vision* **2** 121–131) can be used to plan experiments. One problem is finding a stimulus domain in which the classification is expected to be primarily linear. A second problem is to decide on the required dimensionality of the domain. A third problem is the type and level of external noise. A fourth problem is estimating the level of internal noise. The final problem is deciding on the size of the confidence intervals or the power for correctly selecting among alternative hypotheses. When all these decisions are made, the number of trials needed can be computed. An attempt is made to help the experimenter make these decisions by exploring alternatives and giving examples.

ORAL PRESENTATIONS

AWARENESS

◆ **Duration of visible persistence drifting with a pattern**

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A pattern presented through widely separated slits becomes much more visible when the slits are moved, since the slit width apparently spreads owing to the persistence of retinal image. Visibility is improved, however, even when a pattern behind stationary slits is moved. This phenomenon can be ascribed to an apparent spread of the slit width caused by another form of visible persistence whose retinal position drifts along with the pattern movement. The purpose of this study was to estimate the duration of this drifting visible persistence. Alphabet letters were presented for 320 ms on a 200 Hz display through arrays of stationary vertical slits located above and below the fixation point. The inter-slit interval that gave 50% correct letter identification

was estimated for letters drifting at various speeds behind the narrow slits and for stationary letters seen through stationary slits of various widths. The results suggest that the effects of letter movements were equivalent to physically spreading the slit width from 2 min of arc (one dot width) to the maximum of 7.2–9.7 min of arc. The duration of drifting visible persistence was estimated to be 12–25 ms, which is about one-fourth the duration of conventional retinal persistence estimated by the same technique (57–92 ms).

◆ **Colour spreading beyond luminance edges and space**

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When there is a colour/luminance gradient from the fovea to the periphery, a prolonged fixation leads to colour spreading in this direction. We report a variation in which colour spreads beyond spatial gaps. An array of small coloured squares with luminance contours was displayed on a black background. When the colour/luminance inside the squares had a global colour/luminance gradient from the fovea to the periphery, a prolonged fixation led to vigorous colour spreading in this direction. After 10–20 s of gazing, nearly the entire array appeared to be homogeneous in terms of the inside colour, while the perceptual distinction between background and patches remained obvious. (Artist Julian Stanczak published a series of works with this type of configuration and effect.) The effect is similar to colour spreading or filling-in reported in the literature, but distinctive in that the spreading occurs beyond luminance edges and background space. Contribution of factors such as luminance, gap, presence and collinearity of contours is discussed. We argue that, while the effect is seemingly related to occlusion, early sensory mechanisms, such as edge detection and adaptation, play important roles. The effect has implications on bottom–up processes towards a cortical representation of multiple visual surfaces.

◆ **Asynchronous binding of colour and orientation**

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Recent studies of the perception of stimuli alternating in colour and orientation have yielded apparently paradoxical results. Moutoussis and Zeki (1997 *Proceedings of the Royal Society of London, Series B* **264** 393–399) report that colour is perceived before orientation by around 63 ms. Holcombe and Cavanagh (2001 *Nature Neuroscience* **4** 127–128) find that colour and orientation can be correctly paired at oscillation rates of up to 18.8 Hz, which would seem to place an upper bound of around 14 ms on the amount by which colour is perceived before orientation. At the slow oscillation rates (1–2 Hz) used by Moutoussis and Zeki we observed an apparent asynchrony in the binding of colour and orientation of approximately 50 ms. The extent of the asynchrony was inversely related to the oscillation frequency and was virtually absent at 10 Hz. We found a similar pattern of results whether orientation was defined by luminance or by modulations in colour along cardinal or non-cardinal axes. Our data are consistent with the findings of both previous studies. However, they do not support the involvement of early chromatic segregation postulated by Holcombe and Cavanagh, or the existence of fixed processing latencies between functionally specialised mechanisms postulated by Moutoussis and Zeki. We propose an account of these data based on the temporal response properties of colour-selective and orientation-selective model neurons.

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◆ **The neural correlates of conscious vision**

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At threshold, the same stimulus is perceived on some occasions but not on others—a dissociation between sensory input and conscious visual experience. Cerebral activity which differs when the stimulus has been seen compared to when it has not, correlates with visual consciousness. We have performed parallel functional magnetic resonance imaging (fMRI) and evoked potential (EP) studies on normal sighted subjects while presenting grating stimuli at threshold, integrating the results of the two techniques to study the timing and location of the correlates of consciousness. Our results showed activity in V1 at 100 ms which was present only when subjects had seen the stimulus. 100 ms later, differential activity was found in the left parietal lobe. Differential responses were also found in frontal and parietal regions from 300 ms to 500 ms, in left parietal regions from 200 ms before the motor response and in motor and auditory cortex coincident with the motor response and the second of two sound prompts. The broad temporal distribution

of activations provides evidence for a segregation of function across the network, with activity in V1 reflecting the correlate of consciousness and activity in downstream areas, secondary processes contingent on earlier perceptual processing.

[Supported by the Wellcome Trust.]

◆ **When do we become aware of a stimulus?**

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This question has recently attracted attention, following demonstrations that simultaneous changes in features may not appear synchronous—flashed stimuli lag behind moving ones, and the first flash in a chain appears longer than the rest. Asynchronies of processing under some conditions are well-known, attention and salience can alter the perceived timing of events, and the time at which processing occurs does not necessarily equal the perceived time of stimulation. The question presumes a mythical ‘Cartesian theatre’ where events proceed serially and isochronically with external time. Instead, it is better to understand ‘becoming’ aware of a stimulus as a process, which necessarily takes place over time. How long processing takes depends on the level at which you analyse events. An event is a nested hierarchy of complex spatiotemporal patterns. A high-level event such as a conscious thought possibly extends over several hundred milliseconds. It incorporates several networks settling onto their attractor states (15 ms each), each of which involves multiple cell firings (1 ms each), each of which involves multiple ion channel openings and closings (1 ns each). The answer to the question thus depends on the level of analysis: becoming aware takes longer at higher levels.

PERCEPTUAL LEARNING

◆ **Mechanisms and models of observer state changes in perceptual learning**

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Perceptual learning reflects a change of state of the observer. Doshier and Lu (1998 *Proceedings of the National Academy of Sciences of the USA* **95** 13988–13993; 1999 *Vision Research* **39** 3197–3221); introduced external noise tests and a perceptual template model (PTM) (Lu and Doshier, 1998 *Vision Research* **38** 1183–1198; Doshier and Lu, 2000 *Psychological Science* **11** 139–146) to characterise mechanisms of perceptual learning. State changes reflect improvements in external noise exclusion by template retuning (high noise), stimulus enhancement (low noise), changes in gain-control properties, or mixtures of these mechanisms, which can be distinguished by measuring performance at multiple threshold levels (see Lu and Doshier, 2002, this Supplement). We found that perceptual learning improved external noise exclusion and improved stimulus enhancement. The PTM predicts that these two mechanisms can be decoupled in perceptual learning, while claims of practice improvements in efficiency require full coupling. We consider three cases of perceptual learning of foveal or peripheral orientation judgments with varying amounts of external noise that support the predictions of the PTM. Practice in either high or low noise improves performance in both, but the magnitudes of the improvement in high and low noise are partially, or fully, decoupled.

[Supported by NIMH and NSF]

◆ **Characterising observer and mechanisms underlying changes of observer state with external noise and observer models**

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Four external-noise methods: equivalent input noise (Pelli, 1981, PhD thesis, University of Cambridge, Cambridge, UK), double-pass (Burgess and Colborne, 1988 *Journal of the Optical Society of America A* **5** 617–627), psychometric function (Nachmias and Sansbury, 1974 *Vision Research* **14** 1039–1042), and triple-TVC (threshold versus contrast of the external noise; Lu and Doshier, 1999 *Journal of the Optical Society of America A* **16** 764–778), have led to five observer models: the linear amplifier (LAM; Pelli, 1981, PhD Thesis, University of Cambridge, Cambridge, UK), the multiplicative noise (MNM; Burgess and Colborne, 1988), the linear amplifier + uncertainty (LAUM; Pelli, 1985 *Journal of the Optical Society of America A* **2** 1508–1532), the multiplicative noise + uncertainty (MNUM; Eckstein et al, 1997 *Journal of the Optical Society of America A* **14** 2406–2419), and the perceptual template (PTM; Lu and Doshier, 1998 *Vision Research* **38** 1183–1198) models. Mathematical analyses and empirical data show that both multiplicative noise

and some form of nonlinearity (either substantial uncertainty or a nonlinear transducer function) are necessary to accommodate all the results of the four methods, eliminating LAM, MNM, and LAUM. We prefer the PTM to the MNUM for several reasons. We originally introduced the triple-TVC method and the PTM to characterise the mechanisms underlying performance change due to observer state change (Doshier and Lu, 2002 *Perception* 31 Supplement, 108). A hallmark of the PTM approach is its ability to isolate 'pure' mechanisms. We analyse the signatures of different mechanisms in light of all four different external-noise methods. We discuss empirical results as well as the mathematical properties of performance signatures.
[Supported by NIMH, NSF, and AFOSR.]

◆ **How many functional factors does it take to explain perceptual learning?**

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Performance for many visual tasks improves with practice. We reported that improvements in identifying letters in peripheral vision is due to an increase in sampling efficiency, and not a reduction in intrinsic noise (Chung et al, 2001 *Investigative Ophthalmology & Visual Science* 42 Supplement, 3931). These two factors of the linear-amplifier model (LAM) depend on criterion d' . Here, we examine the functional nature of perceptual learning in a criterion-independent manner by using the perceptual template model (PTM, Lu and Doshier, 1999 *Journal of the Optical Society of America A* 16 764–778). PTM extends LAM by adding transducer nonlinearity and multiplicative noise. Psychometric functions for identifying single letters embedded in 6 external-noise levels were collected over 6 days of practice. Contrast thresholds at $d' = 0.8, 1.7, 2.7$ were determined per noise level. PTM was used to fit each set of threshold-vs-noise-contrast data. Four of the five observers improved with practice and showed a reduction in internal additive noise. Three of the four also showed external-noise exclusion. No significant reduction in multiplicative noise was observed. Removing transducer nonlinearity from PTM caused these factors to be criterion-dependent; however, removing multiplicative noise had little effect. Internal-noise reduction and external-noise exclusion appear to be the common mechanisms of perceptual learning in peripheral vision. Transducer nonlinearity is necessary for these two factors to be criterion-independent.

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◆ **Perceptual grouping by motion precedes relative localisation of visual stimuli**

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A flashed stimulus is perceived as spatially lagging behind a moving stimulus when they are physically aligned. Previously, we have shown that a flash presented near the leading portion of a moving stimulus lags significantly more than a flash presented near the trailing portion (Watanabe et al, 2001 *Journal of Experimental Psychology: Human Perception and Performance* 27 879–894). This asymmetric mislocalisation holds whenever several elements move together and form a unitary percept of an object in motion. Here we examine the time course of the action of common-fate (grouping by common motion) on the asymmetric mislocalisation effect. Observers saw two black vertical bars moving laterally at a constant velocity on a gray background. At various times relative to the onset of motion, a white flash appeared on either the leading or the trailing bar. The asymmetric mislocalisation occurred even when the flash appeared coincident with the onset of motion, namely when no motion existed before the flash. When the velocities of the two bars differed significantly (eg one stationary and one moving), this asymmetric mislocalisation disappeared; thus common-fate was indeed involved. These results suggest that perceptual grouping by motion is computed early enough to impact on the perceptual localisation of visual stimuli relative to moving objects

◆ **A new ideal-observer formulation for perceptual organisation**

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Ideal-observer analysis is typically restricted to the problem of identifying a figure in additive noise. However, visual inference in the natural world is often made difficult not by noise, but by clutter and complexity. Here we develop a new ideal-observer formulation for complex visual problems and apply it to the problem of contour perception. Human observers are presented with a sequence of two images comprising randomly arranged oriented elements. One of the images also contains an element sequence generated by a stochastic contour process whose

parameters are derived from natural image statistics (Elder and Goldberg, 1998 *Perception* 27 Supplement, 11). An adaptive psychometric procedure is used to estimate the complexity (number of elements in the display) at threshold performance for contour detection. The computational complexity of the problem precludes a direct simulation of the ideal observer. Instead we use two sub-optimal machine observers to derive rigorous, tight bounds on ideal-observer performance. Human efficiency, defined as the ratio of display complexity at threshold for human and ideal observers, is found to decrease with the number and, surprisingly, proximity of elements along the contour. The human data rule out strictly local or greedy sub-optimal strategies; we suggest a number of global computational strategies that humans may be using.
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POSTER SESSION

OBJECT RECOGNITION AND CATEGORISATION

● **Object and face perception during image evolution and degradation**

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Interpreting the results of visual object perception experiments is too often ill-posed owing to nonsystematic or sparse selection of stimuli. Random image structure evolution (RISE) is a flexible new technique developed to address this problem directly. In the simplest case, RISE involves the presentation of image sequences depicting the evolution of a coherent image from a random field, along with the reverse sequences depicting the transformation back into randomness. As it systematically samples a subset of the space of possible stimulus images, our image processing strictly preserves low-level attributes such as frequency spectra and luminance; and RISE experiments are designed to provide objectively verifiable measures of the onset and offset of subjects' conscious percepts. In turn, these onset and offset measures can serve as quantitative markers for characterising a number of intriguing perceptual phenomena. Here we describe the RISE paradigm and discuss extensions of this approach which may contribute greatly to the understanding of key aspects of high-level vision. Building on results from our studies of perceptual onset, priming, and hysteresis, as well as findings from imaging and clinical studies, we explore the use of RISE in characterising the neural substrates of object and face perception.

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● **Superstitious perceptions reveal representations of spatial propositions**

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It has been established that a correspondence exists between linguistic and non-linguistic spatial categories (eg Hayward and Tarr, 1995 *Cognition* 55 39–84). However, the nature of the relationship between non-linguistic spatial propositions and their linguistic counterparts (eg 'above', 'below') is a matter for debate. Superstitious perceptions have been used as a method to reveal the properties of unobservable object representations in memory (Gosselin and Schyns, 2001 *Vision Research* 41 2261–2271). In the present study, we applied this methodology to investigate the internal representation of linguistic spatial propositions. Across 20 000 trials, naïve observers were presented with a grey rectangle surrounded by white noise and instructed to detect (a nonexistent) black spot when it appeared 'on top of' the rectangle. The methodology of superstitious perception provides an unbiased context to extract the observer's biases. Observers reported perceiving the black dot on a significant number of trials. With the use of reverse correlation and image analysis, the area representing these superstitious perceptions was revealed in a classification image. Across all observers, images showed an idiosyncratic perceptual space representing the linguistic spatial proposition 'on top of'.

● **Predicting absolute efficiency from classification images**

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Classification images, which show the correlation between noise contrast at each pixel of a stimulus and observers' responses, are particularly simple to interpret when we model observers as noisy linear discriminators. In this case, the classification image is proportional to the linear

template that observers use to discriminate between two stimuli. Departures from linearity (eg stimulus uncertainty) make classification images more difficult to interpret. Here we show that, if observers are noisy linear discriminators, then absolute efficiency can be predicted from the cross-correlation of the classification image with the ideal observer's template. This prediction provides a straightforward test of the hypothesis that all aspects of observers' strategies (eg sampling efficiency and internal-to-external noise ratio) are reflected in the classification image. We tested this prediction with twenty-five classification images in several tasks: contrast increment detection, orientation discrimination, face identification, and discriminations involving illusory and occluded contours. On average the predictions were good, although there were some systematic departures. Hence, most of the observers' performance could be accounted for by the linear strategy encapsulated in the classification images, although some observers' strategies seem to have had nonlinear components that were not captured. We discuss what types of nonlinearities may explain these discrepancies.

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- **How efficiency for identifying objects improves with age**

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We studied the development of object recognition from the age of 2 years to 60 years. We measured contrast threshold in noise for human and ideal observers and calculated the human efficiency. We asked observers to identify the expression of a face (see figure 1 at web address above), or the identity of a letter or a line drawing of an object. We presented the stimuli both right-side-up and upside-down. We find that observers reach adult performance at the age of 12 years with all these stimuli. However, faces, letters, and objects improve by different factors. Efficiency for identifying a facial expression improves only 2-fold (starting at 2.5% and reaching 6%). Efficiency for object recognition improves 5-fold (from 2% to 10%), and the efficiency for identifying a letter improves 75-fold (from 0.2% to 15%). Exposure seems to be the main factor in accounting for the dramatic difference.

- **"It's a highway—no, wait, it's a city": Retinal location specificity of flexible scale use**

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We previously reported that flexible spatial-scale usage can be specific to the left or right visual hemifield (Ozgen et al, 2001 *Perception* 30 Supplement, 6). Here we investigate location specificity further. In a sensitisation stage, observers viewed low-passed or high-passed scenes combined with noise on the unoccupied scale. Observers' task was to categorise the scenes as highway versus city. Subsequently, in a test stage, we interleaved 'hybrid' images, which combined a low-passed and a high-passed scene of opposite categories. Observers' categorisation of a hybrid image indicates the attended scale. In experiment 1, during sensitisation, we assigned one scale to the upper visual field and the other scale to the lower visual field. Observers showed orthogonal, location-dependent, perception of the hybrids (eg low-passed component reported in low-pass-sensitised field and so on). In experiment 2, the visual display was divided into four quadrants. This time each scale was assigned to the diagonal quadrants (upper-left and lower-right versus upper-right and lower-left). Specificity of sensitisation to specific quadrants of the visual field rules out the possibility that it is localised at stages of visual processing where cells are selective for visual hemifields, which suggests that the locus of these effects may be at earlier cortical sites. [Supported by BBSRC Grant 90/S13186 awarded to Paul Sowden and Philippe Schyns.]

- **The processing of semantic information from extrafoveal vision—can and do we do it?**

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We examined whether scene context affects the recognition of objects present within them. Problems with past research reporting inconsistent object 'pop out' have been identified. However, Hollingworth and Henderson (2000 *Visual Cognition* 7 213–235) found new evidence for an inconsistent object advantage in a change-blindness task. We report further experiments in which we examine the issue employing a forced-choice recognition test following a brief presentation with fixation position controlled. We conclude that demonstrations of inconsistent object advantage are very fragile. In experiment 1 we used line drawings of scenes and found a significant advantage ($p < 0.05$) for inconsistent objects in extrafoveal vision. To investigate whether this effect could be due to visual differences between the scenes, in experiment 2 we inverted the

drawings, to inhibit the processing of scene semantics. Results suggest that this does extinguish the advantage, indicating that semantic processing may contribute to the effect. In experiment 3, we used photographs but found no significant differences. To investigate whether this discrepancy is due to the nature of the materials, we created line drawings to match the photographs, which also failed to provide evidence of an inconsistent object advantage. Finally, we present results of our attempts to replicate Hollingworth and Henderson's findings using change-blindness paradigms.

- **The interaction between outline shape and internal details in the recognition of natural objects**

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The role of outline shape and internal details in view-invariant object recognition was investigated in the 2AFC variant of the object-identity-matching experiment. The corpus of depth-rotated images of familiar objects developed by Verfaillie and Boutsen (1995 *Perception & Psychophysics* 57 925–961) was used. According to the goodness ratings of eleven different object views, objects can be clustered on the basis of their coarse structure. The first picture (reference) was displayed for 40 ms, and the view was either canonical or accidental. The presentation of two alternatives (target and distractor) followed either 500 ms or 2000 ms after offset of the reference. The two alternatives were either shaded images or silhouettes, and the view was either the same as the reference or not. The results can be summarised as follows: (i) object views are encoded at different levels according to canonicity; (ii) outline shape and internal details are primed over different time courses; (iii) matching silhouettes with the reference in an accidental view requires access to the knowledge of coarse three-dimensional structure. These results imply the importance of coarse structure in view-invariant recognition.

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- **Do part – whole relations facilitate recognition of scrambled objects?**

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The role of part – whole relations in object recognition was studied by measuring object-identification performance for scrambled image samples (eg Lerner et al, 2001 *Cerebral Cortex* 11 2287–2297). Prior to the experimental test, one group of subjects was trained to encode objects as simple collections of distinctive parts in a view-independent manner (list learners). Another group was trained with the same sets of parts, but with the parts ordered to form meaningful wholes (configuration learners). In the experiment, both groups of subjects had the task to identify the learned objects from scrambled samples. Regardless of the degree of scrambling and its kind (rotation or translation of micro-parts), the configuration learners were faster in correct identification judgments. The advantage of configuration learners was independent of the number of distinctive parts contained in an object. Surprisingly, list learners could handle sample images with object parts forming meaningful wholes faster than their own training samples. The results strongly stress the role of spatial relations between image parts in human object recognition, as supported by other recent studies (Saiki and Hummel, 1998 *Journal of Experimental Psychology* 24 227–251).

- **Categorical effects on visual search for colour**

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We examined whether categorical information about stimuli is used to facilitate performance in a demanding colour search task. 'Difficult' colour search has been demonstrated for targets that are not linearly separable from two or more distractors (Bauer et al, 1996 *Vision Research* 36 1439–1466). In experiment 1, observers performed a nonlinearly separable search where the target fell between the two types of distractors in CIE colour space. When the target and distractors fell within the same colour category, search was difficult. When they fell within three different categories, response times and search slopes were significantly reduced. Experiment 2 replicated these findings in a different region of colour space. In experiment 3, we examined whether a trained observer would benefit from learned information about a novel category while performing a search task. In experiment 4, the search performance of English speakers and speakers of African languages having a common label for blue and green was compared. The African group performed worse than the English group when the task required categorical knowledge of blue and green. The results suggest that categorical information may be used to guide search in a

complex task and that native language indirectly affects performance by constraining access to semantic information about colour.

[We thank Emre Ozgen for designing the computerised training task used in experiment 3.]

- **Physical and subjective criteria of judgments of visual pattern similarity**

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Judgment of similarity and dissimilarity of visual patterns can be determined by different criteria: (a) objective differences (eg one is lighter than the other), (b) subjective impressions (eg one looks more pleasant than the other), and (c) synaesthetic associations (eg one sounds like takeite, and another like maluma). In order to specify the similarity criteria the following data were put into multi-dimensional scaling and cluster analyses: (a) similarity comparison judgments of eight visual patterns, (b) judgments of objective physical features (lightness–darkness, compactness–dispersion, sharpness–softness, simplicity–complexity), (c) subjective judgments of patterns on visual semantic differential scales (scales converged into following factors: evaluation, interestingness, regularity, potency, and activity), and (d) frequencies of phonemes and pseudo-words associated with visual patterns (data collected in Janković and Marković, 2001 *Perception* **30** Supplement, 29). The results show two clear clusters named as takeite and maluma, for all sources of data. Takeite patterns were judged as physically sharper and darker and subjectively more potent, active, and interesting; they contained more phonemes t, z, r, c, k, etc. Maluma patterns were judged as smoother and lighter, less potent and active, but more pleasant; they comprised more phonemes m, a, l, o, n, etc.

- **Multiple constraints on Sino-Japanese character recognition**

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Sino-Japanese character recognition can be facilitated by multiple sources of information, including global shape, central character region, and even initial stroke sequences. We present human experimental data supporting this. Participants in this experiment were primed with different sources of visual information before a character-recognition task. Global shape (overall character shape) and stroke sequence (presenting three initial strokes) both significantly enhanced performance, indicating there exists no single source of information underlying character recognition. Instead, we argue that integration of multiple sources of information governs recognition. We present a neural-network model designed to computationally implement this information integration. In order to model sequential and visual information inherent in this task, we used a simple recurrent network architecture. Input to the networks was a visual representation (12×12 grid) of individual strokes composing a character, presented in sequence. The networks were required to predict the correct character upon each stroke presentation, and were trained on a corpus of 76 characters (learned by first-graders in Japan). Character prediction by strokes in trained networks was facilitated by global shape, and prediction by global shape was facilitated by initial stroke sequences. We discuss these results in view of a multiple-constraints approach to cognition in general.

- **Repetition blindness for subcharacter component reveals different representations of the semantic radical and the phonetic component in Chinese character recognition**

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Repetition blindness (RB) refers to the failure to report the second occurrence of a repeated item in rapid serial visual presentation (RSVP), which may result from token individuation failure of the same activated type (Kanwisher, 1987 *Cognition* **27** 117–143). Adopting the RB paradigm, we examined the representation of the subcharacter component in Chinese character recognition. Three characters and four symbols were presented in RSVP, and the participants were asked to write down the characters. The relationship to the component level of the two critical characters (C1, C2) was manipulated. In experiments 1 and 2, component RB was consistently found when the repeated component was the semantic radical and the phonetic, and when their combinability with other components to form characters was high and low; but no difference in the magnitude of RB was found for high-frequency and low-frequency residual components. When the function and position of the repeated component was further manipulated in experiment 3, RB was found even when the repeated component had a different function and/or different position, except when the radical was on the left, its typical, position. These results indicate that the semantic radical is encoded with its function and position, but not the phonetic.

● **Spatial-frequency spectra of printed characters**

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It is well known that certain spatial-frequency bands are more important than others for character recognition. In particular, Solomon and Pelli (1994 *Nature* **369** 395–397) suggested that perception of letters is mediated by a single bandpass filter tuned to approximately 3 cycles per letter height, with bandwidth of about 2 octaves. This filter is supposed to be an important constraint of human information processing. However, the physical spatial-frequency spectra of letters themselves have not been analysed carefully. In the present study, spatial-frequency spectra of printed numerals (0–9, Arial font) were analysed by methods similar to those developed by Field (1987 *Journal of the Optical Society of America A* **4** 2379–2394) for natural images. Contrast energy per octave-wide bands was found to exhibit maximum at the assumed location of the perceptual filter (3 cycles per character height). It is possible that simple physical properties of printed letters can explain observed bandpass character of their perception.

● **Subitizing in peripheral enumeration**

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It has long been known that people can quickly and accurately estimate, or ‘subitize’, the number of objects in small sets ($N < 5$), but the nature of this process is not clear. Using the eye-movement-contingent display-change technique to manipulate the number of stimuli before and after an intrasaccadic display change, we conducted three experiments to examine some of the properties of subitizing. In experiment 1, we asked subjects to move their eyes to a peripheral display and report the number of objects in that display when they had it in fovea. We found that subjects did not respond faster when the two displays were the same. Therefore no intrasaccadic peripheral preview benefit was found as in word identification and object-naming tasks. Experiment 2 showed that the same subjects could subitize an intrasaccadic peripheral display up to four items. Experiment 3 further showed that the acquired quantitative information can be applied across saccades to compare the numerosity in peripheral and foveal displays for small sets. Overall, these results suggest that enumeration can be done preattentively for small sets but only in a controlled manner. Subitizing is not an automatic process as are word identification and object naming.

● **Visual numerosity judgment: no evidence for subitizing**

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We tested psychophysically the existence of two separate kinds of processing for counting different quantities: the first, parallel, called subitizing, for quantities equal or smaller than four; and the other, serial, for larger quantities (post-subitizing range) (eg Wender and Rothkegel, 2000 *Psychological Research* **64** 81–92). Typically, experiments which found a difference in processing small and large quantities of objects have used accuracy and reaction time as measures. In experiment 1 we measured the contrast threshold for detecting a varying number of gratings (presence/absence). The method of adjustment for contrast was used and interleaved staircases were adopted. The contrast threshold decreased as the quantity of gratings increased. This shows that we detect gratings independently and supports the idea of a single kind of process. In experiment 2 we measured the contrast threshold, by the same method as in experiment 1, for discriminating stimuli varying in number between one and nine. Results show no differences in contrast threshold between the hypothetical subitizing and post-subitizing ranges. Only a slight increase in stimulus intensity was necessary to count the higher quantities (8 and 9 gratings). In the light of our results, we propose that subitizing is due to a floor effect occurring when accuracy and reaction times are taken as measures.

● **Object (a)symmetry: effects of accidental viewpoints**

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An accidental viewpoint is generally believed to impair the perception of an object compared to a canonical viewpoint. The aim of the study was to examine the influence of various accidental and canonical views on the perception of symmetric and asymmetric objects. A sequential matching experiment was performed, in which it was the participant’s task to judge whether two different views could stem from the same object. Accidental views were paired with canonical views, and, as a control, pairs of canonical views were added. The results show differential effects

of object (a)symmetry. In particular, comparisons in which asymmetrical objects were involved were impaired most by accidental views.

● **Availability of intrinsic axis affects viewpoint dependence in spatial reasoning**

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Spatial reasoning of object location has been considered to be viewpoint-dependent—ie there is a cost to generalising a new view from studied views of a location. In much previous work viewpoint dependence was shown when multiple views of the layout of randomly positioned objects were studied. However, it is difficult to derive the intrinsic axis from randomly positioned objects. The present study used a 4-point path two lines of which were parallel. The participants' task was to point to the target from the specified viewpoint. It was expected that the participants would take the axis parallel to the actually drawn parallel lines as the reference frame. The results showed that viewpoint dependence was observed in the single-view-study condition and viewpoint dependence was eliminated in the multiple-view-study condition. Another experiment, in which the task was the sequential matching of a 4-point path, was conducted to examine whether the elimination of viewpoint dependence could also be observed in a form-recognition task. As a result, viewpoint dependence was observed. The availability of the intrinsic axis in addition to the multiplicity of the studied viewpoints might be crucial for viewpoint-independent recognition in spatial reasoning.

● **The role of motion in object categorisation**

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At ECVP 2001 (2001 *Perception* 30 Supplement, 22) we reported that some motion cues were as relevant to object categorisation as spatial cues. In our experiments, novel objects were categorised on the basis of two spatial (colour and shape) and two dynamic properties (action and path). The 'action' of an object referred to its intrinsic motion pattern, whereas 'path' referred to an object's extrinsic motion pattern, ie the route an object took. The task for the participant was to first learn to categorise prototype objects, and then categorise new exemplar objects which varied in number and type of properties in common with the prototype. We were specifically interested whether dynamic properties were used for categorisation as often as spatial properties. In earlier experiments, we found that all properties were relevant for categorisation with the exception of 'path'. We found that this result was not due to 'path' being less salient than other properties. In new experiments, we rendered the 'action' property redundant and found that 'path' was now used for categorisation. We reasoned that path may not have been initially used with action because of temporal-order effects. Our findings argue for a cue-integrated model of object representation.

● **Display effect for object recognition in the mental rotation of line-drawn and dot-defined objects**

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The display effect of opacity and transparency for mental-rotation performance for line-drawn and dot-defined objects were examined. Dot-defined objects were constructed by isolated points on the vertices of each cube. Experiments were conducted to examine the effectiveness of 'perspective display' by using combination pairs of line-drawn and dot-defined objects (Nakayama and Mather, 2000 *Perception* 29 Supplement, 115). When pairs of objects were displayed in perspective, the percentages of correct responses were all significant. Most reaction times (RTs) also increased monotonically with the angular difference between views for stimuli. There was very little difference in RTs for pairs of objects displayed with either a three-dimensional and a two-dimensional mode of presentation with perspective. The exception was a pair of dot-defined objects for two-dimensional presentation of depth rotation. To examine mental-rotation performance for the three display modes—perspective, opacity, and transparency—RTs were compared for the two-dimensional presentation. For line-drawn objects, RTs for the transparent mode were significantly longer than the others. For dot-defined objects, RTs for the perspective mode were significantly shorter than the others. There were, however, no significant differences between the three modes for three-dimension presentation. These results provide evidence that perspective and opacity play a significantly different role as depth cues.

[I am grateful to George Mather for his generous cooperation.]

● **Experiments on identification of moving test objects under threshold conditions of observation**

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The aim of this work was to examine the efficiency of the human visual system under uncertainty about the test object parameters as a function of duration of its presentation. For different intensities of external dynamic noise and for different durations of the test-object presentation we measured the correct identification probabilities of these objects by human observers and by a computer model of the optimal observer. On this basis we calculated the efficiency. We found that an increase of the duration of test-object presentation up to 100–150 ms leads to a decrease in efficiency, then further increase up to 200–250 ms leads to an increase of efficiency followed by its monotonic decrease. For high uncertainty of the initial location of the test object, movement of the object increases efficiency. The faster the movement, the lower the efficiency when the initial location of the object is known in advance. The efficiency is practically independent of advance knowledge of the direction of movement of the object. These results allow us to specify our functional model of the human visual system.

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● **Comparison of measures of complexity of visual objects**

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The complexity of visual objects is one of the most important concepts in visual perception. In modelling experiments, we compared several measures of image complexity using spectral or spatial characteristics of the image, or their combinations. These theoretical results were compared with experimental estimates of complexity for the same set of Chinese hieroglyphs. We used several measures of complexity, among which were a squared perimeter divided by the ink area (Pelli et al, 1994 *Nature* **369** 395–397), the median of an amplitude spectrum, and the product of the square of the median spatial frequency and image area. The only significant correlation between experimental data and theoretical results was found when both spatial and spectral characteristics of objects were taken into account. Thus, in general, the measure of image complexity as a number of harmonics per image needed for recognition is not adequate. One of the fitness metrics was the product of the square of median spatial frequency and image area that was defined by Nasanen et al (1993 *Vision Research* **33** 903–911). The results support the hypothesis proposed earlier by Snellen and Landolt that image complexity is defined by the number of lines in visual objects.

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● **The Gollin incomplete figure test as a masking problem**

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The Gollin test of incomplete figure perception is usually employed to measure the thresholds of recognition in children and adults, and to study a process which provides a basis for the perception of incomplete figures as Gestalts (Foreman and Hemmings, 1987 *Perception* **16** 543–548). Here we suggest that this test—along with such tests as the Poppelreuter test of figure extraction, and the Mooney faces test—may be considered as a visual masking problem. Digital image processing allows us to measure the spatial properties and spatial-frequency spectrum of the absent part of the image as a mask. We compare incomplete masking with other traditional types of masking. Using a noise paradigm, we have measured the signal-to-noise ratio for incomplete figure perception in normal participants and in neurological patients. This is the most powerful aspect of this new approach. Clinically, the new paradigm may provide a quantitative measure of agnosia. We have developed the hypothesis that some forms of visual agnosia arise primarily from an especially high level of noise within higher visual processing, including memory systems. We classify this type of agnosia as ‘filtration agnosia’. The concept of incomplete figure perception as noise filtration is therefore important for clinical purposes.

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● **Associative priming in the right cerebral hemisphere**

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The representation of visual forms of objects was investigated in a priming experiment where prime and target pictures were independently presented to the left or right visual fields (LVF or RVF). Associated exemplars were employed as related pairs and a base line was provided by neutral pairs. These stimulus pairs were temporally separated by a stimulus onset asynchrony of 250 ms. When the target was a meaningful picture, subjects were required to press keys with both index fingers (object decision task; ODT). The faster of the two responses was recorded as reaction time (RT). When the target was a meaningless picture, subjects were required to withhold their response. RT to LVF targets was faster when preceded by a related prime in the same visual field. This effect was not found in any other visual-field conditions. Priming effects are thought to reflect semantic memory, and semantic priming effects have been reported when prime and target words were projected to the RVF. ODT with pictures as stimuli does not require semantic information but makes use of stored visual forms of real objects. The result suggests that visual forms of objects are associated with the process of visual perception.

● **Categorical perception requires spatially distributed attention**

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A yes/no discrimination task and a 4AFC task were performed with letter-like stimuli in order to demonstrate that categorical perception only occurs for letters of the alphabet under conditions of spatially distributed attention. The requirement of spatially distributed attention was studied further under conditions requiring focused (within-category stimulus pair) or distributed (between-categories) attention. Reaction times were measured for detection of an 'odd' stimulus in a display of either 2, 4, or 6 letter-like stimuli. Two different modes of perception were demonstrated. Sloped plots of reaction times, indicating no categorical perception, were produced for within-category stimulus pairs. Flat plots of reaction time, indicating categorical perception, were produced for between-categories stimulus pairs. A 4AFC experiment was carried out with simple vertical lines in order to assess whether categorical perception would occur with a 4AFC design regardless of the stimuli used. Vertical lines would not be expected to demonstrate categorical perception. No categorical perception was found for these stimuli. Spatially distributed attention is necessary for categorical perception of letter-like stimuli to occur.

COMPLEX MOTION

● **Perceptual history influences neural responses to face and body postures**

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The interpretation of a visual scene is profoundly influenced by information other than that in current visual input. One important source of information is the perceptual history, ie specific visual patterns that were on the retina in the immediate past. We provide direct evidence that the response selectivity of a substantial number of cells in the anterior part of the superior temporal sulcus (STSa) of the macaque monkey to the sight of static head and body postures under natural viewing is controlled by the sight of immediately preceding body actions. The cells responded vigorously to the sight of a face or body posture that followed a particular action, but not when it followed other actions. The effective action or posture presented in isolation or in different sequences failed to produce a response. We argue that the 'vocabulary' of actions and body postures coded for by single STSa cells is much larger than previously thought, encompassing also specific action–posture sequences. Our results demonstrate that cells in temporal cortex could support the understanding of natural body actions, which are continuous and complex sequences of postures with linking movements, and could support the formation of expectations about impending behaviour of others.

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● **Learning to discriminate artificial biological-motion patterns**

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Biological movements can be easily recognised from point-light stimuli. It is still unclear how the visual system accomplishes this recognition. Some properties of biological-motion recognition,

eg the inversion effect, suggest that recognition is based on learned templates. This hypothesis predicts that humans should be able to learn arbitrary new movement patterns, even if they do not correspond to movements of a real biological organism. We tested this hypothesis in a very direct way by creating artificial movements through motion morphing. Using a special technique, we computed linear combinations of very dissimilar prototypical movements that were obtained by motion capturing. Such linear combinations specify very similar low-level motion information as that specified by the prototypes, but define movements that cannot be realised by a human. The stimuli were presented as point-light walkers in a discrimination experiment with a pair comparison paradigm. By varying the weights of the linear combination we could gradually vary the spatiotemporal similarity of the stimuli. We found a robust learning effect for the discrimination task, but only if subjects received feedback during training. Also, we found partial transfer between upright and rotated figures. We interpret these results as evidence that learning might play a fundamental role in the recognition of biological motion.

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● **A review of gender recognition from gait**

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It is often claimed that point-light displays of gait provide sufficient information to recognise properties such as gender. We have examined several aspects of the recognition of gender from point-light displays including: (i) a meta-analysis of the numerous experimental studies of gender recognition; (ii) examination of the predictions of the centre-of-moment calculation of Cutting and colleagues based on human hip and shoulder dimensions provided by anthropometric databases; (iii) examination of the recognition of gender from point-light arm movements. Results from the meta-analysis indicate performance generally equivalent to the low levels of performance originally reported by Kozlowski and Cutting (1977 *Perception & Psychophysics* **21** 575–580), for gait-only displays, and that recognition increases when gait is coupled with other activities. Results from the centre-of-moment calculation indicate that centre-of-moment information is sufficient for recognising gender, but owing to overlapping distributions performance is not perfect. Results from the human perception of arm movements indicate that arm movements alone are sometimes sufficient for recognising gender. Taken together, these results indicate that gender recognition is typically a difficult task that is potentially aided by incorporating information from the entire body. [Supported by the Nuffield Foundation, the Wellcome Trust.]

● **Movement and faces in the perception of emotion**

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In this research we asked the question: how does information from movement combine with information from facial expression to produce the perception of emotion? In the perception of emotion from human movement, people can recognise emotions accurately (Pollick et al, 2001 *Cognition* **82** B51–B61). Moreover, two independent and continuous dimensions appear sufficient to describe the psychological representation of emotion from human movement. From still photographs of facial expressions the perception of emotion is even better; additionally this perception has been characterised as being much more categorical in nature (Etcoff and Magee, 1992 *Cognition* **44** 227–240). In order to see how these two types of information are combined, we created 3-D humanoid models with facial expressions—happy, sad, angry, and neutral. We then used human movement data captured from an actor as he performed expressive movements to animate the motion of the model. By combining facial expressions and movement from separate emotions, we were able to create hybrid emotional displays. Both hybrid and non-hybrid movements were shown to observers who were asked to categorise the emotions and rate the intensity of emotion. The results showed complex interactions between information from facial expressions and movements and these are discussed further.

● **The imitation and perception of morphed arm movements**

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Humans are very good at perceiving each others movement. Current theories of imitation suggest that people have the ability to detect fine differences in the actions of others, store them in a motor vocabulary, and later transform them into covert action. We collected 3-D arm movement data from thirty individuals performing over-arm throws. A movement was defined to have three segments whose duration defined the temporal structure of the throw. A cluster

analysis of the thirty participants revealed three distinct temporal patterns, and we chose two exemplars from each temporal pattern. These six individuals were morphed in pairs; new movements were created with a temporal morphing technique that morphed between and past the temporal structure of each of the other individuals. These 'self-other' morphs were used in two subsequent experiments. In experiment 1, we examined participants' ability to visually discriminate self among the 'self-other' morphs. We found that ratings of self reliably decreased as morphing level increased. In experiment 2, participants imitated each 'self-other' morph five times. Regression analysis revealed a good correspondence between the temporal structure of the presented morph and the imitated movement. Our findings suggest that not only are people able to detect fine variations in movements but also to imitate them.

● **Analysing and imitating facial movement**

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Faces are dynamic channels of communication, and it is therefore important to understand how this information is encoded and represented. Computer-generated faces, or avatars, are becoming increasingly sophisticated, but are visually unrealistic and their control remains problematic. Previous work has implemented complex three-dimensional polygonal models, often generated from laser scans, with intricate hard-coded muscle models for actuation of speech and expression. Driving the avatar through mimicry involves tracking a real actor's facial movements, usually through markers physically attached to the face or by locating natural feature boundaries. Here we show that principal components analysis of the dense optic-flow fields generated by facial movement delivers interpretable component movements of the face. This allows the comparison of natural varieties of movement with standard facial action coding systems such as FACS [Ekman and Friesen, 1978 *Manual for the Facial Action Coding System* (Palo Alto, CA: Consulting Psychologists Press)]. Optic flow is calculated by using a biologically motivated optic-flow algorithm (Johnston et al, 1999 *Proceedings of the Royal Society of London, Series B* **266** 509–518). Principal components are visualised by warping static images of the face. This fully automated technique yields a virtual avatar onto which the movements of an actor can automatically be projected for convincing performance-driven animation, with no need for markers.

● **Neural model for the learning of biological motion**

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Several experimental results suggest that biological movements are encoded on the basis of learned template patterns. Recent theoretical work has shown that a biologically plausible hierarchical neural model that encodes biological movements in terms of learned prototypical patterns provides a consistent explanation for many experimental results on biological motion perception [Giese and Poggio, 2002 (submitted)]. The model postulates that biological-motion patterns are encoded in terms of sequences of complex shapes and optic-flow-field patterns in the ventral and dorsal pathway. The underlying neural circuits predict future form and optic-flow patterns from the previous stimulus sequence. Electrophysiological experiments (eg Markram et al, 1997 *Science* **275** 213–215) have provided evidence that Hebbian plasticity in the cortex depends critically on the relative timing between the presynaptic and postsynaptic spikes. We tested how far such time-dependent Hebbian plasticity is an appropriate mechanism for the learning of sequence selectivity in the recognition of biological movements. In addition, we tried to derive psychophysically testable predictions that would allow us to validate the predictive coding hypothesis that underlies our model.

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● **View invariance in facial motion**

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Motion may play a large role in the generation of face representations. Facial movement has been shown to facilitate recognition, categorisation of identity, and gender judgment. Dynamic information can be isolated from spatial information by driving a 3-D computer-rendered facial model with the movements of an actor. It has been shown that the perception of static faces is viewpoint-dependent (Hill et al, 1997 *Cognition* **62** 201–222). To investigate viewpoint-dependence in dynamic faces an avatar was animated by using actor's movements. Subjects were shown

a full-face facial movement. They were then asked to judge which of two rotated moving avatars matched the first face. Test view, orientation, and the type of movement (rigid + nonrigid versus nonrigid) were manipulated. Nonrigid movement alone produced an advantage for upright faces and no effect of view. Rigid and nonrigid movement presented together produced an advantage for upright faces and a decline in performance for larger test rotations. No interaction was found. This suggests that nonrigid facial movement is represented in a viewpoint-invariant manner while the addition of rigid-head movements encourages a more-viewpoint-dependent encoding.

● The role of motion cues in the recognition of animals

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Previous studies have found that adding biological-motion information to an animal-form cue does not raise recognition thresholds (Bellefeuille and Faubert, 1998 *Perception* 27 225–235). The findings that both form cues and biological-motion cues can be used to recognise animals, but that no additive advantage is gained from combining them, has added further weight to the idea that biological motion represents a specialised and separate process within the visual system. Further findings from neuroimaging and neuropsychological studies have also provided support for the presence of separate biological-motion processing pathways (Grossman et al, 2000 *Journal of Cognitive Neuroscience* 12 711–720). We carried out a series of experiments using static and moving natural images of animals. Natural images were used to preserve all potentially important kinematic cues. These images were presented in differing densities of random punctate interference. The results are discussed in the light of previous findings that there is no additive advantage to recognition performance if form cues are combined with biological-motion cues. In order to assess top–down influences on biological-motion perception, subjects were tested for simple animal phobias. Preliminary results suggest that biological motion may play a role in the rapid detection of the feared animal in simple animal phobias.

● Searching for gender-from-motion

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Biological motion contains many forms of information. Observers are usually able to tell ‘what’ action is being performed (eg walking versus running), ‘how’ it is being performed (eg quickly versus slowly), and by ‘whom’ (eg a young versus an old actor). We used visual search to explore the perception of gender-from-motion. In the first experiment, we used computer-animated, fully rendered human figures in which the structural and dynamic information for gender were factorially combined. In separate blocks, observers were asked to locate a figure walking with a male or female gait among distractors having the same form but opposite motion. In the second experiment, point-light walkers moved along random paths in a 3-D virtual environment. Observers were asked to locate a figure walking with a male or female gait among distractors with the opposite motion. In both experiments, the set size was varied between 1 and 4, and targets were present on 50% of the trials. The results suggest that (a) visual search can be used to explore gender-from-motion, (b) extraction of gender-from-motion is fairly inefficient (search slopes often exceed 500 ms item⁻¹), and (c) there appears to be an observer-gender by target–gender interaction, with male observers producing lower RTs for female targets and vice versa.

● Perception and production of biological motion: a cross talk?

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Recent findings suggest that perception and production of biological motion share a common representational network. Here, we investigated whether biological motion perception is restricted by early disorders in production of body movement. Combining the simultaneous-masking paradigm with brain imaging, we assessed sensitivity to biological motion in former preterms (13–16 year olds, 27–34 weeks gestational age). The participants differed in their locomotion ability from normal to a complete walking disability. In the stimulus-known-exactly detection task, they judged the presence of the camouflaged point-light walker. Irrespective of an ability to produce movement, patients with similar extent of parieto-occipital periventricular

leukomalacia (PVL) exhibit nearly the same sensitivity to biological motion. Sensitivity correlates negatively with the extent of PVL in the parieto-occipital complex, whereas neither the severity of motor impairment nor the extent of lesions along the pyramidal tract significantly relate to the sensitivity index. The findings suggest that perception of biological motion is not substantially affected by an observer's early restrictions in body movement. Instead, the findings favour the assumption that the common network for perception and production of biological motion might be inherent for the brain. Recording of task-driven magnetoencephalographic (MEG) brain activity provides further evidence for clarification of this issue.

● **Time to contact from disparity and looming cues: observers don't always respond to the most immediate cue**

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Our ability to judge the time to contact (TTC) of an approaching object depends on both binocular disparity and looming cues. When these cues are put into conflict in a ball-catching task (Rushton and Wann, 1999 *Nature Neuroscience* 2 186–190), an immediacy bias is observed: subjects respond to whichever cue specifies the shortest TTC. Here we tested whether the immediacy bias is also observed for different tasks and different ranges of motion. TTC judgments were measured in two tasks: (a) an estimation task where subjects were shown an approaching object and asked to press a button to indicate when it would hit them, and (b) a discrimination task, where subjects were asked which of two intervals contained the stimulus with a shorter TTC. Looming and changing disparity specified TTC, and could be manipulated independently. If an immediacy bias were present, then the perceived TTC should be consistent with the shorter of the TTCs specified by disparity or looming. We found that for discrimination at a fast speed, and for estimation, the data did not follow this pattern. Instead, they suggested that performance was affected by the relative reliability of the two cues. Cue reliability appears to be an important factor in determining which cues dominate the perception of TTC.

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● **Detection of motion in depth: poor motion thresholds using LCD stereogoggles**

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3-D motion can be generated on a 2-D computer monitor by presenting different motion signals to each eye. Two techniques for stereoscopic motion presentation are widely used: stereogoggles (present alternate frames in the motion sequence to each eye) and the mirror stereoscope (directs different images to the left and right eyes). Our aim was to determine whether observer responses to real-world 3-D motion are comparable to their responses to computer-generated motion when using the two different presentation techniques. Observers undertook a direction-discrimination task. For the real-world task, we moved an LED backwards and forwards in depth relative to a stationary fixation point. Ray tracing was used in the computer tasks to generate the same pattern of motion across the retinas as in the real-world task. Probit analysis was applied to the data in order to determine thresholds. We found that thresholds for computer-generated motion viewed through stereogoggles were up to ten times higher than thresholds for real-world motion. Thresholds for motion viewed through the mirror stereoscope were similar to real-world thresholds. We suggest that the temporally interleaved presentation of motion associated with stereogoggles may have raised thresholds in this task.

● **MEG study of the processing of 2-D motion and 3-D structure-from-motion**

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Using MEG, we explored the dynamics of the cerebral activity while subjects were viewing either incoherent (2-D) motion, or coherent motion evoking a 3-D object. Both stimuli had the same spatiotemporal distribution of speed amplitude. We analysed the responses to the different types of visual transition between black screen, static dots, incoherent motion, and 3-D structure-from-motion. Both the 2-D motion onset (from static dots) and the 3-D object onset (from random motion) induced large-wave responses in occipito-parietal regions, with the largest amplitude of response for the second one. Nevertheless, when comparing different transitions, the early responses appeared to depend very much on the preceding display (black screen or static dots)

rather than the appearing stimulus (incoherent or coherent motion). In contrast, the later responses, especially the ones detected during the steady state of motion (corresponding to a periodic speed variation) and correlated with motion variation, appeared to be quite different for the random and 3-D motion. For the random motion, the activity was mainly occipital, while the 3-D stimulus induced more parietal and central activity. We suggest that this late and periodic response may be more specific of the processing we are interested in than the early and transient responses to the onset of the stimuli.

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- **Spatiotemporal volume visualisation, exploration, and perception**

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A new system for three-dimensional (3-D) visualisation and interactive exploration of spatiotemporal information in image sequences is introduced. Spatiotemporal volumes from video and image sequences can be constructed and studied by generating cuts through, and projections of, the volumes. By making use of direct volume rendering and a real-time volume rendering card, such as VolumePro, one can interactively view and explore spatiotemporal patterns and structures. This can significantly aid the perception and understanding of spatiotemporal events. It also facilitates the construction of mental kinetic models, eg the movement of the ping-pong ball in a table tennis game. A major advantage of using such a system is its ability to provide instant visual response to the observer's actions to manipulate and explore the volume. However, interpretation of spatiotemporal representations and displays is generally quite difficult because we are simply not used to treating spatial and temporal information in a unified way. The same system can also be used to study spatiotemporal data coming from multiple video cameras simultaneously viewing the same object/scene. This 4-D data set, made of multiple 3-D spatiotemporal volumes, provides a very compact representation. Its rendering leads to a highly 'unusual' image, since it shows in a single display how an object/scene changes over time and from a number of viewpoints.

- **Naïve impetus, the launching effect, and representational momentum**

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Naïve impetus theory [McCloskey, 1983, in Gentner and Stevens (Eds) *Mental Models* (Hillsdale, NJ: Lawrence Erlbaum Associates)] suggests (a) the act of setting an object in motion imparts 'impetus' that maintains motion, and (b) this impetus gradually dissipates. In the launching effect [Michotte, 1963 *The Perception of Causality* (New York: Basic Books)], a moving launcher that contacts a stationary target which subsequently moves is perceived as causing the motion of that target. Representational momentum involves displacement in remembered location of a previously viewed target (Hubbard, 1995 *Psychonomic Bulletin & Review* 2 322–338). In three experiments, we used representational momentum measures to test a naïve impetus explanation of the launching effect. Observers viewed variations of launching effect displays, and representational momentum of targets was measured. In experiment 1, relative velocities of the launcher and the target varied, and target displacement was influenced by launcher velocity. In experiment 2, launcher velocity did not influence displacement of a target that remained stationary. In experiment 3, displacement of a launched target decreased with increases in distance travelled by that target. Displacement patterns were consistent with naïve impetus theory and the hypothesis that observers believed impetus from the launcher was imparted to the target and dissipated with target motion.

- **Representational momentum with and without a non-target context**

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The memory for the final position of a moving target is displaced forward in its moving direction (representational momentum: RM). The purpose of this study was to investigate RM with and without a stationary context. Additionally, memory for the position of a stationary context was examined with and without a moving target. When both target and context stimuli were present, the target moved toward, passed, and moved away from the context. The target and context vanished simultaneously at various relative positions. An auditory cue told participants which position to judge, the target or the context. In the control conditions, a single stimulus, target or context alone, was presented. Results showed that RM with the context was much smaller than RM without the context, and that insignificant RM was observed after the target reached the

context. They suggest that the context served as a reference point and that memory for the final position of the target became accurate. Moreover, memory for the position of the context was displaced towards the final position of the target when two to-be-memorised positions were not close to each other. Therefore, it is suggested that the positions of the target and context are dynamically coded and memorised.

● **When ‘when’ matters: sensory and decisional components in divergent categorisation of identical visual speeds**

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Categorisation of sets with over-represented high or low visual speeds strongly depends on whether mainly frequent or infrequent speeds occur early in the presentation series. The frequency and primacy effects combine or cancel each other yielding divergent categorisation of identical speeds (Sokolov et al, 2000 *Perception & Psychophysics* **62** 998–1007; 2002 *Perception & Psychophysics* **64** 561–569). Here, we sought to disentangle sensory and decisional components in the divergent categorisation of the same visual speeds. By using three categories (slow, moderate, or fast), participants judged five visual speeds of a single dot ($3-9 \text{ deg s}^{-1}$) presented one per trial in either positively (20-14-8-4-4) or negatively skewed sets (4-4-8-14-20; low speeds come on the left). Mainly frequent or infrequent speeds occurred on the initial trials (either combined or opposed frequency and onset order). Thurstonian analysis of response distributions revealed that when mainly frequent speeds occurred early in a series (frequency/onset-order combination), the sensory effects of distinct speeds were markedly enhanced. The response bias’ changes were confined solely to locations of single criteria. We conclude that the divergent categorisation of the same visual speeds is of sensory rather than decisional origin.

● **Can telepresent observers learn to take account of enhanced motion parallax?**

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There is evidence suggesting that telepresent observers make more precise depth judgments when the gain between observer head motion and a head-slaved camera unit is increased, but that systematic biases are made on tasks requiring recovery of Euclidean geometry [Hibbard et al, 2001, in *Contemporary Ergonomics 2001* Ed. M Hanson (Taylor and Francis, London) pp 523–529)]. Here, we used such a task to examine whether observers can learn to take account of enhanced motion parallax. The design comprised three phases: pre-adaptation, where motion parallax gain (MPG) = 1; adaptation, where MPG = 0.5 or 2; and post-adaptation, where MPG = 1. Telepresent observers were required to adjust the magnitude of a depth interval (specified by self-produced motion parallax) so that it matched a 2-D interval specified by two lights (set at 15, 20, or 25 cm) in an otherwise blacked-out scene. In the adaptation phase, the ratio of head motion to camera-unit motion was changed to 0.5 or 2 and observers set depth intervals between 15 cm and 30 cm repeatedly until a performance criterion was reached. Feedback was given in the adaptation phase in the form of another light at the correct depth. Comparison of pre and post settings shows clear evidence that observers learned rapidly in both adaptation conditions.

● **Perceiving a stable environment by using immersive virtual reality**

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The ability of moving observers to perceive their environment as stable has previously been investigated with mechanical devices that yoked an object’s movement to the subject’s movement (eg Wallach et al, 1974 *Perception & Psychophysics* **15** 339–343). Using an immersive virtual-reality system we have extended these observations. Subjects fixated a spherical textured object at a distance of approximately 1.5 m while walking from side to side (approximately ± 1 m). The sphere rotated about a vertical axis with different gain factors: a gain of +1 caused it to always face the observer; a gain of –1 caused an equal and opposite rotation; a gain of zero means the object is static in world coordinates. In a forced-choice paradigm, subjects judged the sign of the gain, which was varied randomly from trial to trial. The threshold for detecting rotation of the object (defined as the standard deviation of the fitted cumulative Gaussian) and the bias (the rotation at which the object appeared static) were both affected by the visual context in which the target was presented. Thresholds were lower and the bias was closer to zero when the object was embedded in a rich-cue environment.

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● **Effects of local landmark information on performance of wayfinding**

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There are two crucial factors for successful wayfinding: to learn routes in an environment and to acquire a cognitive map of it, namely an exocentric representation of the environment. The belief is that we learn a cognitive map through exploring the environment with an egocentric view. In this research, the effects of egocentric local landmark information on performance of route learning and on cognitive-map acquisition has been investigated, with wayfinding in an urban environment simulated by a quadrilateral maze in a virtual-reality display. Landmarks were located either at intersections or along streets. Performance of route learning was evaluated by the time spent in finding a designated goal in the virtual maze. Performance of cognitive-map acquisition was evaluated by the time spent in moving back from the goal to the starting position. The results showed that addition of local landmarks in the maze led to statistically better performance of route learning and cognitive-map acquisition. The improvement was more pronounced when landmarks were located at intersections than when they were located along streets. These results suggest that the transformation from an egocentric view to an exocentric representation of the environment requires landmark information besides temporal change of the view.

● **Planning a route with multiple targets in a regionalised environment**

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Hierarchical encoding of space influences distance estimations, directional judgments, spatial priming, and recall of landmarks. Yet little is known about the impact of regionalised (hierarchical) spatial memory on route planning and navigation. By employing navigation tasks with multiple targets, we studied the influence of regions as well as spatially clustered targets on route planning. Subjects navigated through a virtual environment composed of 16 places arranged on a regular 4×4 grid. Places were grouped into 4 square islands. All places could be identified by associated objects. The places were connected in a city-block topology by streets or bridges. Subsequent to exploration and training, subjects were asked to navigate the shortest route connecting three of the places (targets) within the environment. When two of the targets were neighbouring each other (spatial cluster), while the third target was sole, subjects preferred routes that first passed the cluster. When two of the targets not only formed a spatial cluster but were also located on the same island (regional cluster) the preference strongly increased. This region effect provides additional evidence for hierarchical theories of spatial representations. We also discuss the contribution of region boundaries and target clusters to route planning.

● **The role of motion parallax in the localisation of targets included in static or dynamic scenes**

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We tested subjects' accuracy in locating landmarks by exploring coupling between their head movements and the resulting optical transformations produced in computer-generated scenery. Stimulus trials either simulated locomotion across a tree-filled plane while the subjects were looking at a particular tree (dynamic conditions), or corresponded to a fixed viewpoint (static conditions). As the coupling introduced a lateral motion parallax effect recognised as a determinant cue for distance perception, we expected that subjects could use it for better localisation. Sixteen subjects were shown short motion sequences, representing a fixed line of three simplified trees plus two additional trees with varying positions to be reproduced. Three conditions (with coupling, without coupling, replay of the coupling) were used. After viewing each static or dynamic sequence in perspective, subjects were asked to replace both the two additional trees on a plan view. In static conditions, spatial localisation was effectively improved. In dynamic conditions, however, better performances were found with the replay of coupling rather than in coupling itself. We may assume that a proper use of artificial lateral motion parallax would require more training for a moving observer than for a static one.

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VISUAL ARTS AND HISTORY

● The strategy of visual irritation: perception and representation as subjects of contemporary art

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Ambiguous stimuli, which undermine the mechanisms of human perception, lead to phenomena which contradict the fundamental conception of a coherent, stable, unambiguous, and controllable world. These phenomena are experienced as worrisome visual 'disturbances' or 'illusions' and result in the subject becoming aware of, and reflecting on, the disturbed aspect of perception. Such a disturbance of the process of contemplation is examined here as a strategy, purposefully applied in contemporary art (eg by James Turrell, Anish Kapoor, Sonja Braas, Joan Fontcuberta) and is presented on the basis of some exemplary works. Under 'normal' conditions, phenomenal experience has the quality of 'transparency'—it seems to provide direct contact with, and information on, the world. The same also holds for such external media, which are understood as 'documentary' or 'objective'. Disturbances of perception, in contrast, cause a subjectively experienced irritation, which questions, on a (meta-)level of reflection, the assumed 'transparency' of the respective representation. An understanding of the representation as representation is provoked, and a conscious reflection upon its characteristics becomes possible. The artistic strategy of irritation therefore can serve to question certain characteristics of conscious perception in itself or the perception or idea of something or the nature of other (external) forms of representation.

● Representation and perception of pictorial space in a work of art: role of monocular and binocular depth cues

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We have studied the pictorial space distortions between artistic representation of space, using monocular cues, and observation of the same picture in natural conditions, while using binocular cues in peripheral vision. The picture was viewed monocularly or binocularly as a plan representation (zero disparity). A binocular probe, consisting of two series of random-dot stereograms vertically flanking each side of the picture, was adjusted in depth to be compared with the impression of depth given by this picture. Two pictures were selected, depending on the monocular cues used. Pictures were observed from a distance of 60 cm, directly in front or at $\pm 5^\circ$ and $\pm 10^\circ$ of head rotation, and displayed in colour or in a grey scale. Variations of perceived depth were plotted against head position. The curves show that the perceived depth depends on colour cue in monocular vision but not in binocular vision. It increases in monocular vision when perspective cues are used. Binocular curves are symmetric and exhibit an extremum for central position, whereas monocular curves are strongly asymmetric. The results are interpreted on the basis of weight variation of the depth cues used in the pictorial representation—break point, accommodation, asymmetric convergence, vertical disparities, nature of the visual direction used—and on the basis of surrounding viewing conditions.

● The effect of movie editing on the perception of a movie: changing of the perceptual organisation of two shots

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The montage theorists in Russia have claimed that movie editing has a great power to give shots a meaning that is not contained in them unedited. Suzuki and Osada (2001 *Perception* 30 Supplement, 29) tested how movie editing affects the impression of a movie. The aim of the current study is to investigate the effect of the order of presentation of the shots on the perception of a movie. Fifteen observers took part in our experiment and were asked to give responses to twenty-four different movies composed of six shots, three of which were 'human face' shots and three 'object' shots. Our results suggest that the order of two shots often has an effect to make the shots perceptually organised. In those cases when the shots were perceptually organised, the movie showed one complete event in combination of two shots, and observers perceived strong combination between the two shots. In those cases when the shots were not perceptually organised, the movie showed different events in each shot, and observers inferred the relationship between the two shots. We propose that the uncompleted acting of the character in one shot may facilitate perceptual organisation between these shots.

● **Handles on visual perception**

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Within the dictionary definition of 'perception', we think that we can all agree that artists should have something to contribute. The problem of communication between the disciplines lies in what is excluded from their terms of reference. If research into vision, as optically guided action, is conducted exclusively through the proof environment, the possibilities suggested by intuitive recognition will continue to be excluded. We would maintain that vision science is missing half of the possible handles available for a more in-depth understanding of visual perception.

The vast majority of vision scientists are effectively blind! A small number of vision scientists agree with that shocking statement. It is important to be perceptive, to have the courage of your perceptions. When artists stopped painting 'pictures' and started to paint what they saw and how they saw, their records (paintings) contained small 't' truths which have been accruing into an intuitive 'understanding' of visual perception. This new paradigm fits like a mask over some of the most recent developments in vision science. We have a new form of illusionary space on a 2-D surface. Artists have been observing the intricacies of visual field and can establish a perception loop with an observer of their work, that transcends traditional picture space.

● **People look at pictures in accordance with their perceptual maps**

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In accordance with our model of visual recognition, the eye scanning of a visual scene is determined by a 'perceptual map'—a distribution of 'perceptual weights' (PW) of main fragments in a scene. In this report, we propose a formal model of the creation of a perceptual map which is based on a detailed analysis of many pictures of famous artists. We can extract four main visual parameters that form PW of any image fragment: (i) size, (ii) colour and brightness contrast, (iii) visual complexity, and (iv) direction and distance from the initial fixation point. We propose a simple computer version of the model which has the following main steps: (a) low-frequency filtering; (b) extraction of image regions which differ from the background; (c) calculation of PW as the weighted sum of size, contrast, complexity, and position values for all extracted fragments; (d) estimation of the obtained perceptual map and choice of the point with maximal PW; (e) a shift of attentional focus at this point, an eye movement at this point, and reduction of corresponding fragment PW at the perceptual map. After visual description or recognition of fixated fragment, the procedure is repeated for others sites. The described model can explain the phenomenon of scan-paths in eye movements.

● **Herman Ludwig Ferdinand von Helmholtz: The Glasgow dimension**

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The links between Helmholtz and Scotland are more extensive and more important than is commonly supposed. We have recently described his encounter with golf at St Andrews (Wade and Swanston, 2001 *Perception* 30 1407–1410). We add to this preliminary account by considering the significance of his documented inability to estimate middle to long range distances correctly and his experience of the effect of practice on the acquisition of perceptual–motor skills. We also contribute to the pictorial record of his encounter with golf, and the scientists with whom he played (Alexander Crum Brown, Thomas Huxley, and Peter Guthrie Tait). Helmholtz's visits to Scotland were principally to meet William Thomson (later Lord Kelvin) in Glasgow; they took place in 1860, 1863, and 1871, although the two men first met in 1855. They shared interests in vision as well as mathematical physics. On his last visit, Helmholtz was also able to explore the effects of vertigo on Thomson's yacht Lalla Rookh off the west coast of Scotland: "I allowed myself to seek amusement in balancing myself up and down on deck, in wavering grace, and occasionally setting cataracts of sea-water to run off my waterproof". Helmholtz was a good sailor, but it was a fall on a return voyage from America, in 1893, that precipitated his death in the following year. The Professor of Physiology at Glasgow University, John Grey McKendrick, wrote the first biography of Helmholtz, five years after his death.

CROSS-MODAL INTERACTIONS

● **Influence of gain factors and attention on sensor fusion in the perception of self-rotation**

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We investigated how optic flow and physical body movements are integrated in the perception of upright self-rotation. In sensor fusion experiments, large intersensory conflicts often lead to bimodal response distributions (ie response is dominated by any one of the input modalities). We hypothesised that the selection of dominant modality can be controlled by attention.

Subjects were rotated by means of a Stewart motion platform. Optic flow stimuli were presented on a video projection screen. For each trial, first a concurrent rotation of the platform and the visual stimulus was presented. Subjects were then asked to reproduce either the perceived visual rotation or the perceived platform rotation using a joystick. During rotation reproduction, a gain factor between the rotation speeds of the two cues was applied. The results show that visual cues exert a greater influence on the vestibularly reproduced rotation than vice versa. When the difference between visual and platform rotation was great, response distributions for each of the two attentional conditions were unimodal, but the means of the distributions of these two conditions differed significantly from each other. This shows that the fused, unimodal percept can be shifted by an attentional bias toward the attended cue.

● **Visual and auditory integration in sport performance**

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In everyday life, our actions are guided by a variety of perceptual cues: visual, auditory, kinesthetic, tactile, olfactory. It is well known that a correct cognitive integration of these cues leads to a more effective representation of our environment. In sport performance, cross-modal integration plays a crucial role. In particular, the integration between visual and auditory cues can be systematically studied from a cognitive perspective, in the attempt to individuate the guidelines to build mental strategies. Although practicing sports intuitively seems to be a highly visually dependent behaviour, and visual inputs tend to dominate other modalities, we experimentally studied the role of the auditory information, and its potential implications to enhance the performance in a few sports. We systematically manipulated the visual and auditory stimulation to evaluate their relative influence on performance. Our results seem to be coherent with literature claiming that auditory information is an essential factor to guide motor action in sport activities. This kind of suggestion, emerging from applied studies in sport activities, offers important indications for developing cognitive models about mental strategies in sport.

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● **A cross-modality interaction between the appearance of random-dot patterns and the perceived loudness of auditory stimuli**

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Our previous study suggested that the change in optical spreading velocity of a disk-shaped dot pattern is one of the important factors determining the perceptual impression, 'looming' or 'expansion'. However, there is some evidence demonstrating that event perception is affected by multi-modal factors. For example, loudness is closely related to visual motion in depth. In the present study we examined whether or not loudness would influence the mode of appearance of a spreading dot pattern, attempting to make clear the relative contributions from auditory and visual modalities to perceptual impressions. In experiment 1, we changed both the optical spreading velocity and the loudness. Participants were asked to report whether the spreading dot pattern was perceived as either 'looming' or 'expanding'. The results demonstrated that usually 'looming' was dominant over 'expanding', but when the spreading velocity was kept constant and the loudness was lowered, 'expanding' was reported more frequently than 'looming'. In experiment 2, in which the same stimuli as in experiment 1 were used, participants were asked to report how the auditory stimuli were perceived. The results showed that when loudness level was kept constant, the velocity of optically spreading pattern affected the impression of loudness.

● **Spatiotemporal influence of shape information acquired through non-visual modality on the perception of bistable surfaces**

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We investigated the phenomenon of multistable surface perception in which surface shape can be perceived in several stable forms from an identical stereogram (Idesawa, 1990, in *Proceedings of IJCNN-90* pp 17–20; Shi and Idesawa, 1997 *Journal of Robotics and Mechatronics* 9-2 98–103). In these earlier reports, we investigated the perception of stereograms that were preceded by stimuli representing real or illusory surfaces. Remarkable differences in the spatio-temporal influence of the previously displayed surfaces were observed between the real and illusory conditions, probably reflecting a difference in visual processing stages (Idesawa et al, 2000 *Perception* 29 Supplement, 33). We also observed influences of tactile and auditory stimuli on the perception of multistable surfaces (Nakamura and Idesawa, 1999, in *Proceedings of 4th IS Symposium on Sensing and Perception* pp 139–144, in Japanese). Here, we investigate the influence of voice stimuli on the perception of shape from multistable 3-D surfaces. We found that the visual system is sensitive to voice stimuli and needs about 500 ms to make a correct visual response. Interestingly, these influences appear larger for the mother tongue than for a foreign language. These results probably reflect a difference in the language processing stages in the brain.

● **Cross-modal interaction in event perception and temporal perception**

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When an object moves over some distance, its perceived duration is correlated with its perceived distance and velocity. This phenomenon implies that temporal perception is closely related to event perception. In our previous study, we found that the perceptual impression of ‘looming’ was dominant over that of ‘expansion’ when the optical spreading velocity of dot pattern increased, whereas the opposite tendency was observed when the spreading velocity decreased. In addition, we demonstrated that loudness changes induced by auditory stimuli presented simultaneously with the dot pattern would be one of the critical factors determining this kind of event perception. In the present study, an attempt was made to examine whether the cross-modal interaction affects event perception and temporal perception under the same conditions as in our previous study. Optical spreading velocity was changed in three ways: accelerating, constant, and decelerating; and also loudness was changed: increasing, constant, decreasing, and a condition where no auditory stimulus was presented. Each of the participants was asked to judge the perceived event as well as the perceived temporal length. The results showed that there was cross-modal interaction similar to that observed in our previous study, and that ‘looming’ made perceived duration longer than ‘expansion’ did.

ADAPTATION AND AFTEREFFECTS

● **The validity of Emmert’s law tested for the afterimage in real and virtual environments**

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We examined the validity of Emmert’s law by measuring perceived size and distance of the afterimages in real (RE) and virtual (VE) environments. (In this study, Emmert’s law is interpreted to state that the perceived size of the afterimages is directly proportional to perceived distance.) VE was made from the CAVE virtual reality system consisting of four 3 m × 3 m screens. The stimulus, an afterimage produced by flashing with a stroboscopic lamp, was disc-shaped and 1 deg in diameter. Observers were asked to report the perceived size of the afterimage projected on a real or virtual screen at various distances (from 1 m to 24 m) by a reproduction method and to estimate the perceived distance by a magnitude estimation method. Both the results for nineteen observers in RE and for six observers in VE showed that the perceived size of the afterimages was directly proportional to the perceived distance. These results explicitly indicate that Emmert’s law is valid in virtual space as well as in real space for the viewing distances used. We suggest that the relation between the perceived size and distance of the afterimage is accounted for by the size–distance invariance hypothesis.

● **The lateral effect of a luminance-modulated annulus on a foveal afterimage. Long-range interaction in human vision**

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There is neurophysiological and psychophysical evidence that visual stimuli are not only locally processed, but that they are also subject to lateral (global) modulations from the surround. We have recently found that when a flash-induced afterimage was projected onto a steady central disk of up to 40 deg diameter, a surrounding annulus that was modulated in luminance induced brightness and size pulsations in the afterimage. The foveal afterimage changes temporally in counterphase to the annulus; ie when the annulus is bright, the afterimage becomes dark and smaller, and when the annulus is dark, the afterimage becomes bright and larger. The astonishing aspect with this new phenomenon is that the afterimage changes in the same directions as when the central background disk is modulated in the same phase as the annulus. This appears counter-intuitive because a bright annulus makes the disk become darker owing to simultaneous contrast, while for the same reason, a dark annulus makes the disk become lighter. This observation speaks against an afterimage modulation due to simultaneous contrast on the disk. Since stray light may also be ruled out as a cause for this effect, the physical luminance changes of the annulus must affect the afterimage through a lateral process. Where this process occurs, in the retina or in the cortex, or both, is not known. The strength of the effect has been measured by a compensation method, where the perceived modulation of the afterimage was cancelled by counterphase modulation of the disk background. After interocular stray light was taken into account, the fall-off of the effect with distance from the fovea was determined.

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● **Fast adaptation mechanism of visual system to rapid retinal illuminance changes**

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One of the most important abilities of the human visual system is its adaptation to slow and to fast changes of the illumination on the retina. Here we consider the mechanism of fast adaptation and artifacts caused by this process. In our research we used the method of mathematical modelling. We found that: (i) a fast adaptation algorithm begins to operate when the axis of view moves from one part of the observed scene to another, leading to great changes of illumination in the fovea; (ii) the Broca–Sulzer effect is the consequence of this fast adaptation mechanism; (iii) joint operation of algorithms of slow and fast adaptation provides the transformation of signals that leads to the matching of dynamic ranges of the optic nerve and transmitting signals through it. We have developed a mathematical model of primary stages in the visual system describing the processes of fast adaptation. Our research allows us to make quantitative explanations of all basic effects of the Broca–Sulzer phenomenon which could not be understood for many years. Results of calculations based on the derived formulas are in good agreement with experimental data.

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● **Flicker and interocular transfer of the motion aftereffect**

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The motion aftereffect (MAE) exhibits interocular transfer (IOT): adapting to motion using one eye can yield an MAE when the other is tested. With static test displays the IOT is around 30%–50% of that generated monocularly. The situation is said to be otherwise when a flickering or phase-alternating test pattern is observed. IOT can be 100% of monocular MAEs, and considerable theoretical import has been posited in this difference between static and dynamic test patterns. It is easy to overlook the importance of any implicit boundaries in displays, and they can influence the results obtained in subtle ways. When all the frames of reference in the display are recognised, then novel ways of assessing the influence of stimulus factors on MAEs can be applied. If displays of the type introduced by Swanson and Wade (1992 *Perception* 21

569–582) are used, then the effects of adaptation and test processes can be teased apart. We have adopted this method for examining the influence of flicker (phase alternation) on the test regions that were adapted to motion and those in which the MAE is expressed. All conditions involved adaptation to two laterally moving surround gratings, and the duration of the MAE was measured with three static gratings, three flickering gratings, three gratings in which the surrounds alone flickered, and three gratings in which the centre alone flickered. Each of the four conditions was measured monocularly and for IOT. A flickering test field does make the MAE more difficult to see, but it does not appreciably influence the pattern of results in comparison with a static test. The ratios between monocular and IOT MAEs are similar, being around 30%. Flicker reduced the durations of MAEs but a similar pattern was found for comparisons between monocular and IOT conditions.

● **Velocity dependence of the interocular transfer of dynamic motion aftereffects**

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It is well established that motion aftereffects (MAEs) show interocular transfer (IOT). Adaptation effects generated through one eye can be detected through the other eye. Different methods have been shown to give different IOT magnitudes, varying from no to almost full IOT. In this study we examined to what extent IOT of the MAE varies with velocity of the adaptation stimulus. We measured the strength of the MAE by a nulling method. The aftereffect induced by adaptation to a moving random-dot pattern is compensated during a brief, dynamic test period by the same kind of motion stimulus of variable luminance signal-to-noise ratio (LSNR). The LSNR nulling value was determined with a Quest staircase procedure. We found that velocity has a strong effect on the magnitude of IOT. For low velocities, IOT is small, with a minimum of about 15% at a velocity of 1.5 deg s^{-1} . IOT then increases with increasing velocity, although it never reaches 100%. On average, for velocities ranging from 0.75 deg s^{-1} to 24 deg s^{-1} the transfer was about 50%. The finding that dynamic MAEs do not transfer completely for all velocities suggests that different speed-tuned systems of different binocularity play a role.

● **Relative motion aftereffects caused by adaptation to random dynamic and motion noise**

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Adaptation to a stimulus comprising black-and-white random texture (SN) embedded in dynamic 'noise' (DN) produces the jitter aftereffect (JAE) when a test stimulus comprising just SN is viewed. Similar to the 'Ouchi' illusion, the JAE is illusory, small-amplitude, random relative movement of the unadapted region in the test stimulus, and is caused by fixational eye movements. In the present experiments, a trial was a 40 s adaptation period preceding a 20 s test. The adaptation stimulus was a 3.5 deg diameter disk composed of high-contrast SN with elements varying from 0.01 deg to 0.67 deg. Directly surrounding the disk was an annulus, 7.5 deg in diameter, containing DN which changed at a frequency from 2 Hz to 88 Hz. The test stimulus was a 7.5 deg diameter disk of SN. JAE strength peaked for element sizes around 0.07 deg, and diminished markedly for rates below 15 Hz. A directional and linear DN produced stronger JAEs than either radial or circular DN. When DN comprised small-amplitude, triangular oscillation (1.8 Hz to 15 Hz), velocity of movement (ceiling at 4 deg s^{-1}) rather than frequency determined JAE strength. JAE adaptation can be dissociated from the MAE and is sensitive to frequencies beyond fixational eye movement.

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● **Motion aftereffects from illusory movements of second-order contours**

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Subjective contours can be made by an offset in a grating, and also by a row of alternating black and white dots. We find that when such contours drift across the visual field, their perceived motion is different in direction from their actual motion. We tested whether this illusory motion produced motion aftereffects. Dotted or phase-offset tilted contours drifted horizontally across the visual field, and observers reported their perceived direction by setting an arrow controlled by a keyboard. The moving field was then replaced by a test field of static random dots. Observers reported the perceived direction of the motion aftereffect by using the arrow. The subjective contours appeared to move in directions biased to the directions along the contours, not to the

directions orthogonal to the contours. The motion aftereffects were always opposite in direction to the perceived motion. We conclude that the illusory motion we found is produced purely by the first-order motion-processing system, which does not respond to the whole, second-order contour.

● **Unraveling levels of motion adaptation: attentional modulation**

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Adaptation to complex motions can result in threshold elevation even at locations that have not been directly stimulated. The elevation for these so-called phantom aftereffects, however, is not as high as for the stimulus areas that have been stimulated directly (eg Snowden and Milne, 1997 *Current Biology* 7 717–722). This suggests a differential contribution of local and global gains. We used Snowden's stimulus and tested how attending to a specific quadrant influences the local and global gains. Observers attended to one of the two quadrants containing rotating dots. The coherence thresholds were determined at three locations: the attended motion area, the unattended motion area, and the phantom area. The results are in line with previous findings: threshold elevations were found in both the stimulated and phantom areas. However, the unattended motion area showed much less adaptation as compared to the passive viewing condition, while the attended area showed no or a small positive effect (deeper adaptation). The effect on the phantom area was ambiguous. So far, the results seem to indicate that attentional selection does not lead to an increase in adaptation at the attended location but to a decrease in adaptation in the areas that have not been selected, indicating that attention has a suppressive effect on non-attended areas.

● **The effects of adaptation and surround on colour-constancy measurements**

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Our object was to examine how adaptation time and a remote surround influence perceived colour. We evaluated colour appearance using monocular sequential asymmetric colour matching. Ten Munsell samples (value/chroma 7/4 and neutral N7, size 2 deg) were presented on a neutral background (N7, size 20 deg), under two test illuminants (A, S); all were computer-simulated. In a parallel study, a neutral diffuser was introduced as an additional surround. The test samples on the N7 background with or without the surround were viewed for 0.2, 1, 5, 30, or 60 s. Test samples were matched by reference samples under illuminant C; matching time was not restricted. The effect of adaptation time was quantified by calculating the Brunswick ratio (BR), and the colour difference $E(L, a, b)$ between the perceived colour of samples under the test and standard (C) illuminant. The colour difference $E(L, a, b)$ increased (10%–50%) with increasing adaptation time. It levelled off or decreased for the longest duration, but BR did not reach 1. However, without the surround, the colour difference $E(L, a, b)$ increased monotonically (10%–70%) and BR asymptotically approached 1. We conclude that maximum constancy requires 60 s of adaptation. A remote dark surround reduces adaptation and reduces constancy. [We thank M Jurkutaitis for helpful assistance.]

● **Colour memory under changing illumination**

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In the natural world, colour constancy typically requires that object colours be compared to remembered colours, across temporal changes in illumination and context. To assess the effects of colour memory on colour constancy, we performed the following experiment. Colour samples were printed on matte white paper with a calibrated colour inkjet printer and displayed in a light-tight viewing box under calibrated illumination, whose spectrum was systematically varied with coloured filters. On each trial, the observer: (i) adapted to a white card under neutral illumination (60 s); (ii) viewed and memorised the reference sample under neutral illumination (60 s); (iii) adapted to a white card under the test illumination (the memory interval of variable duration); (iv) selected a match from the test samples viewed under the test illumination. The test samples were arranged in 4×4 grids on black backgrounds, and varied in hue or saturation only, in perceptually equal steps. We found that colour memory deteriorates under changing illumination, but hue memory deteriorates more than saturation memory. This result is not explained by a tendency to match sample luminance and chromaticity across illuminations rather than reflectance; therefore, saturation constancy is greater than hue constancy when colour memory is required. [YL is supported by a Unilever Studentship.]

NATURAL IMAGES

- **Rapid categorisation of faces and animals in upright and inverted natural scenes: no need for mental rotation and evidence for a selective visual streaming of upright faces**
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In a go/no-go paradigm, participants had to respond when a natural image flashed for 20 ms contained a target. Targets were alternatively animals (but not humans) or human faces. Sixteen blocks of 96 trials randomly mixed upright and upside-down images. With animal targets, half of the non-targets contained faces and vice versa. With upright photographs, behavioural performance was virtually identical in both tasks (96.3% correct for animals versus 96.4% for faces, 382 ms mean RT in both cases). A small inversion effect was present for both categories but stronger for faces (2% accuracy drop in both cases but a mean RT increase of 13 ms for animals versus 23 ms for faces). Early ERP (event-related potential) differential effects (from 57 ms) between faces and non-targets were entirely due to low-level visual differences. A discrimination process started around 140 ms for faces and 149 ms for animals, a latency that was not affected by inversion, leaving no time for any mental rotation process. For all stimuli, the image status (target or non-target) was reflected at around 150 ms except for upright faces where it appeared later, at 188 ms. This suggests that, with a non-target status, upright faces are processed more deeply than inverted faces or animals.

- **Very early event-related-potential effects in rapid visual categorisation of natural scenes: distinguishing the role of low-level visual properties and task requirements**
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Humans can visually categorise objects remarkably rapidly. Using the high temporal resolution of visual evoked potentials (VEPs), a growing number of researchers have reported 'very' early (50–100 ms) categorisation effects linked to the selective processing of relevant objects like faces. However, these differences could just be due to low-level physical properties between stimulus categories. Evidence for such an interpretation was given by van Rullen and Thorpe (2001 *Journal of Cognitive Neuroscience* 3 454–461), who introduced a dual-task paradigm that allows the comparison of EEG signals evoked by the same natural images but with different task-related status. They found that very early VEP differences were due to physical differences between categories and were unrelated to the task. Here we extend these findings by reporting new evidence from three experiments with natural images. In an animal/non-animal categorisation task, luminance or contrast image modifications were directly reflected in very early (60–80 ms) VEP differences, while sparing task-related effects. Finally, using the dual-categorisation task paradigm in which faces and animals could alternatively have a status of target or distractor, we found again that early effects only expressed low-level visual differences between image categories, as they totally disappeared when physical properties were equated. Longer latency task-related effects were preserved.

- **Argument for scene categorisation with image amplitude spectra**
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We investigated the hypothesis that amplitude without phase-spectra study is sufficient to classify natural scenes. Many researches (eg Morgan et al, 1991 *Biological Cybernetics* 65 113–119) have shown that semantic information is mainly contained in the phase spectrum and not in the amplitude one. Meanwhile, most of psychophysics or modelling works use the amplitude spectrum. Twenty noisy natural-scene pictures were shown both to human subjects and to a classification model which reproduces different human visual processes. After a retinal preprocessing, a 'cortical' filter which codes images by energy within seven spatial-frequency bands and seven orientations, was applied. This encoding was compared to the typical image encoding of each category. Four classes of noise were built. Their spectral characteristics were city-like noise (horizontal noise, H_n) or beach-like noise (vertical noise, V_n), neutral (isotropic noise) or unnatural (white noise).

It was expected that recognition would be easier for pictures composed with congruent noises (beach with V_n or city with H_n) than for noncongruent ones. Human behaviour and our simulation show that amplitude without phase spectra is sufficient to make natural-scene classification.

● **The scene sketch**

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Studies in scene recognition have shown that, while we can identify a real-world scene in a single glance, we do not necessarily encode details about its component objects. The visual system rapidly extracts a rough sketch of the scene which selects essential contours and textural regions while delivering spatial and semantic information. A sketch is a simple representation of an image that conveys its meaning. A sketch representation for machine vision should follow these constraints: (i) low dimensionality—the sketch should be drawn from a small number of features; (ii) relevance—the representation should capture the information that preserves the identity of the image; (iii) similarity mapping—similar images should be close together in the space defined by the sketch features. Here we propose a holistic sketch representation of real-world scenes that combines textural and spatial information without segmenting the image into objects or regions. The dimensionality of the representation is independent of the complexity of the image (eg number of objects, etc). Our sketch representation encodes the structure of the whole scene and is robust enough to provide both the basic-level semantic category of a scene and its mean depth.

● **Phase information in the recognition of natural images**

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Fourier phase plays an important role in determining global image structure. For example, when the phase spectrum of an image of a flower is swapped with that of a tank, we usually perceive a tank, even though the amplitude spectrum is still that of the flower. Similarly, when the phase spectrum of an image is randomly swapped across frequencies, that is its Fourier energy is randomly distributed over the image, the resulting image becomes impossible to recognise. Our goal was to evaluate the effect of phase manipulations in a quantitative manner. Subjects viewed two images of natural scenes, one of which contained an animal (the target) embedded in the background. The spectra of the images were manipulated by adding random phase noise at each frequency. The phase noise was the independent variable, uniformly distributed between 0° and $\pm 180^\circ$. Subjects were remarkably resistant to phase noise. Even with $\pm 120^\circ$ noise, subjects were still 75% correct. The proportion of correct answers closely followed the correlation between original and noise-distorted images. Thus it appears as if it was not the global phase information per se that determines our percept of natural images, but rather the effect of phase on local image features.

● **Detection thresholds of grating patches depend on the second-order statistics of their surround**

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The visibility of a grating patch is altered when it is surrounded by another grating. Here, we determined the visibility of a grating patch when it is surrounded by complex images of varying second-order statistics. The 86% correct detection threshold of a 256 grey-level grating patch ($1.00 \text{ deg} \times 0.13 \text{ deg}$, spatial frequency 6 cycles deg^{-1}) was measured when it was surrounded by different complex images ($4 \text{ deg} \times 4 \text{ deg}$). The surrounding images were derived from either real natural images, or from random luminance patterns, filtered to different second-order statistics. The detection threshold of the grating in natural images was found to be highest when the surrounding images had the characteristic statistics of real-world scenes. The detection threshold of a grating surrounded by filtered random-luminance patterns was highest when the surrounds were, in comparison to natural scenes, slightly de-correlated. The results show that the detection thresholds of gratings are affected by the statistics of their surrounding stimuli. The thresholds are higher when the surrounding stimuli have the statistics of natural images.

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- **Studying the representation of natural images with the use of behavioural reverse correlation**
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What information do humans use during the identification of complex natural scenes? To address this question, we employed a technique described originally by Gosselin and Schyns (2001 *Vision Research* **41** 2261–2271), which identifies image regions diagnostic for visual-recognition tasks. We applied this method to a task where subjects had to discriminate natural images. On each trial, one of four images was shown behind an occluding mask punctured by multiple randomly located Gaussian windows. Diagnostic image regions were computed by comparing masks that resulted in correct performance with masks leading to incorrect performance. During different sessions, we used either a constant-stimuli protocol with a fixed number of windows, or a staircase protocol to adjust the number of windows as a function of behavioural performance. In general, depending on the particular natural image, different regions were revealed as diagnostic. Results for the constant-stimuli and the staircase protocols were in good agreement. For the constant-stimuli protocol, we found that subjects' behavioural performance improved with training for some natural images. Diagnostic information generally did not show dramatic changes, although sometimes particular image regions became diagnostic with learning. These results demonstrate that reverse correlation can be used to reveal diagnostic regions in complex natural images.

- **The independent components of binocular images**
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The response properties of cells in the visual cortex appear to be optimally tuned to provide a sparse, economic representation of natural images. Independent-component analysis was performed to determine how a similar representation of binocular information might be achieved. Binocular photographs of natural scenes were captured with a binocular video camera. For each photograph, the camera was fixated on a point of central interest in the scene. Independent-component analysis was performed on a large number of samples extracted from the binocular image pairs. The resulting independent-component filters showed clearly defined receptive fields, and were tuned to both orientation and spatial frequency. A substantial proportion of binocular filters, showing similar response properties for the left and right images, were obtained. Close analysis of these filters revealed interocular differences in both the position and structure of their receptive fields. Filters were obtained that differed in phase, orientation, and spatial-frequency-tuning between the left and right images. These results show close similarities to physiological results (DeAngelis et al, 1995 *Perception* **24** 3–31; Bridge and Cumming, 2001 *Journal of Neuroscience* **21** 7293–7302), and suggest that the visual system might use a number of strategies to encode binocular disparity.

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- **Abstract representation of natural scenes and the role of fixation**
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Recent change detection research has demonstrated that we do not retain and fuse the pictorial content of successive fixations. Whilst point-by-point transsaccadic representation appears unlikely, more abstract forms of information may be retained. We tested extraction of different types of information from 2-D and 3-D natural scenes under conditions of competitive, parallel processing, as are present in real-life situations. We found that multiple types of information are extracted and integrated into representations of our surroundings, over 10 s of viewing. Time courses and relative extents of extraction vary between the different types of information tested. The inclusion of eye-movement measures in analyses reveals a crucial role of fixations in information extraction. Information assimilation into short-term representation appears to be dominated by the foveal retina. Our data indicate that information is integrated from multiple foveations of objects in scenes and imply differences in the profiles of extraction from successive fixations between the different types of information. We present a framework in which representation faithfulness and richness depend crucially on fixation history of that part of the visual scene. Hence we propose an efficient representation in which 'areas of interest' are represented more richly than other locations in the scene.

● **Colour constancy under illuminant changes with 3-D and 2-D views of real scenes**

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The aim of this work was to compare the degree of colour constancy obtained with 3-D real scenes and their 2-D copies. In the experiment, observers viewed a real 3-D scene or its 2-D planar projection through a large beam splitter that projected into the scene the image of a 3-D test object consisting of a coloured cube or, respectively, a 2-D copy, so that the object appeared part of the scene. The illuminants on the scene and on the test object were controlled with high precision by independent computer-driven light sources. In each trial, the illuminant on the scene changed abruptly from 25 000 K to 6700 K at 1 s intervals and the illuminant on the object changed either consistently or inconsistently with the scene illuminant by a variable degree quantified within CIE 1976 ($L^*u^*v^*$) colour space. Observers had to decide whether the object underwent a change in its materials. Colour-constancy indices were very similar for the 3-D and 2-D scenes, suggesting that 3-D cues have a limited role in surface colour perception.

● **Colour constancy under illuminant changes on real three-dimensional scenes**

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Colour constancy has typically been measured either with computer-generated stimuli on a monitor screen or with real objects but in experimental designs with limited cues. The aim of this work was to measure colour constancy with coloured objects in real three-dimensional (3-D) scenes under changes in illuminants. In the experiment, observers viewed a 3-D scene through a large beam splitter that projected the image of a 3-D test object consisting of a coloured cube into the scene so that it appeared part of the scene. The illuminants on the scene and on the test object were controlled with high precision by independent computer-driven light sources. In each trial, the illuminant on the scene changed abruptly from 25 000 K to 6700 K at 1 s intervals and the illuminant on the object changed either consistently or inconsistently with the scene illuminant by a variable degree quantified within CIE 1976 ($L^*u^*v^*$) colour space. Observers had to decide whether the object underwent a change in its materials. Colour-constancy indices obtained in this way were generally very high, corresponding to perfect constancy with some objects.

● **Material recognition under artificial illuminations**

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Humans can easily recognise materials, such as metal, paper, or plastic, under various illuminations. The difficulty in clarifying how this is done lies in the fact that a given image of a material can be produced by any combinations of surface reflectance property and illumination. It has been suggested that the visual system utilises some regularities of real-world illuminations to recover the surface reflectance (Fleming et al, 2001, MIT AI Memo 032). If so, material recognition could be difficult under unrealistic illuminations. To examine this prediction, we made a room uniformly illuminated from all directions in three-dimensional space, which rarely happens in the real-world. Subjects classified various objects in this room on the basis of the perceived materials. We found that the ability to distinguish metal was entirely lost. Metal objects were classified as paper or as unknown, which implies that the recognition of metal depends on real-world illuminations. Their colours were judged as yellow or gray, not gold or silver, when they were not perceived as metal. Other materials, such as rubber or plastic, were also not recognised well, while paper or textured materials like wood were recognised under the artificial illuminations. Thus, the dependence of material recognition on real-world illuminations varies with materials.

COMPUTATIONAL MODELLING

● The spatiotemporal autocorrelation spectrum bridges energy-based and feature-based accounts of motion

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Energy-based and feature-based ('informational') models of visual motion look at motion stimuli from differing perspectives. The energy-based account considers motion detection as being equivalent to sampling sections of the spatiotemporal energy spectrum. In the feature-based account, detectors seek nearest-neighbour feature matches across stimulus frames. Each of these accounts can explain a wide range of effects—suggesting that there is an underlying link between the two perspectives—but they are each blind to certain manipulations. Energy models have difficulty accounting for density effects in random-dot kinematograms (RDKs), while feature-based models are oblivious to temporal manipulations of the stimulus. The spatiotemporal autocorrelation spectrum is an intriguing link between these two different accounts. It is closely related to the energy model (the autocorrelation spectrum and the energy spectrum are a Fourier transform pair), yet it also has an intrinsically 'informational' (or probability-based) component. We show here how the spatiotemporal autocorrelation spectrum is affected by diverse RDK manipulations, and discuss implications for the energy-based versus feature-based distinction between motion models.

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● Marr's bars, zero-crossings, and motion

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This presentation tracks the use of the 'zero-crossing' in modelling motion direction. Marr and Ullman (1981 *Proceedings of the Royal Society of London Series B* **211** 151–180) first introduced the use of 'zero-crossings' into motion detection. Their computation of direction selectivity was based on computing the time derivative

$$\frac{d}{dt} D_2 G(x, y) I(x, y) ,$$

where $D_2 G(x, y) I(x, y)$ is the Laplacian of a Gaussian convolved with the spatial intensity of an image, and the time derivative is measured at the zero-crossings of the spatial output. There are several problems with their model, eg (i) direction sensitivity, (ii) deciding which segments of zero-crossings to use, (iii) motion direction is not invariant with respect to contrast. Since then the use of zero-crossings has been confined to defining two-dimensional image regions the motion of which is then tracked. Recent modelling is based primarily on computing spatiotemporal energy that takes no account of zero-crossings. However, a model proposed by Bowns (2002 *Vision Research* **42** 1671–1681) shows how a number of key ideas in spatiotemporal models can be implemented by extracting zero-crossings at the component level. These ideas include computing the 'intersection of constraints'; introducing 'apparent' spatial frequencies that affect perceived motion direction but which are not present at the component level; and computing the 'vector average' of components.

● A real-time implementation of a neuromorphic optic-flow algorithm

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We have developed a real-time vision system for computing dense optic-flow fields. The system is based upon the multichannel gradient model of human motion perception (Johnston et al, 1999 *Proceedings of the Royal Society of London, Series B* **266** 509–518). The model employs a large number of space–time filtering operations with biologically plausible receptive fields. The implementation permits us to visually demonstrate, in real-time, the outputs from three temporally filtered channels and multiple oriented spatially filtered channels. Combinations of filter outputs can be seen to yield direction-sensitive and velocity-sensitive measures and the amalgamation of the outputs can be combined to produce optic-flow fields. Our demonstration uses a CCD camera for live-image acquisition and a dedicated image-processing engine to compute the filter responses and optic flow. The system is interactive and provides us with a graphic insight into the types of operations going on in the visual cortex.

● Simple-cell contrast responses and the transducer function

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The 'dipper' result for psychophysical contrast discrimination may be due to a nonlinear transducer function and/or multiplicative noise. V1 simple cells show both of these features. First, the contrast response function, as described by the equation

$$R = R_{\max} \frac{C^q}{C^q + c_{50}^q}$$

has the required accelerating/decelerating shape, where R is a response of the neuron to contrast c , R_{\max} its maximum response, c_{50} the contrast at half saturation, and q is ~ 2 . Second, variance of contrast responses increases as twice the mean response. Our model consists of groups of neurons ($n = 1-18$) with the above properties and with a set of c_{50} values measured from cat simple cells. It simulates a 2AFC experiment, with a Bayesian pooling rule to infer the contrast of the two 'intervals'. The parameters of the contrast response function were varied and the model produced a dipper in all cases except when $q < 1.5$. The presence of a hard threshold produced a large effect, and was found necessary to match the depth of the psychophysical dipper. To match the smooth shape of the psychophysical dipper, it was necessary to use more than one cell, covering a range of c_{50} values. This finding questions the appropriateness of using a one-channel transducer function to model psychophysical data.

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● In search of the Holy Grail: a unified spatial-detection model

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Although there exist some models that can predict detection curves for specific patterns like periodic gratings, the development of more advanced models is important because we can try to reason about the processes involved. In an earlier paper (du Buf, 1992 *Spatial Vision* 6 25–60) it was shown that a multichannel model, once calibrated with a sine-wave contrast sensitivity function (CSF), can predict CSFs of other gratings like square-wave, but not detection curves of disks. Recently we developed a modular software package that allows us to easily modify nonlinear models based on complex Gabor filters, first calibrating them with CSFs of 1-D sine-wave gratings, circular (co)sine gratings, or circular Bessel functions, and then predicting detection thresholds of other patterns. Simple models based on a nonlinear summation of Gabor filter responses can predict correct CSFs of many periodic gratings (eg square-wave, square-wave with missing fundamental, trapezoidal), as well as weighted Hermite polynomials. They can also predict many contrast interrelation functions obtained by superimposing specific patterns like lines and edges on a (co)sine background. Correct detection thresholds of disks can only be predicted when including other processes, like collinear and lateral inhibitions. One possible conclusion is that different patterns might be detected at different levels in the visual system.

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● Colour opponency by means of feedback from horizontal cells: a role of amplification by their nonsynaptic membrane

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Feedback from horizontal cells (HCs) to cones controls cone output (glutamate release) and is considered a possible mechanism of the colour opponency (CO) in the outer retina. However, unlike feedforward versions, such a scheme for CO meets with some logical difficulties. Physiological functions usually attributed to CO require the opponent signal to be independent of brightness ('pure' CO). For that, the transmitter release must not depend on the intensity of the illumination. A paradox is that in this case HCs apparently do not receive any information about the illumination also and so cannot provide the necessary feedback. The paradox can be settled by assuming that the feedback loop has to possess practically 'infinite' gain. In that case, the output cone signal proves to be rather stabilised, while the HC potentials reflect variations of illumination and supply the necessary signal for feedback. A substantial amplification of graded potentials in HCs is possible owing to voltage-dependent properties of their nonsynaptic membrane. Appropriate 'negative' resistance of the HC membrane was described by Byzov et al (1977 *Vision Research* 17 265–273) in fish retinas, but its function remained unclear. Our model of the feedback via HCs possessing such membrane indeed simulates the necessary 'pure' CO.

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● **Estimation of reflectance properties following colour segmentation (colour-constancy model based on colour segmentation data)**

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Our aim was to develop a working software package incorporating colour segmentation and colour constancy algorithms in the same framework based on a generalised linear theory of reflection. To solve the colour-constancy task means to estimate the spectral reflectance properties of objects (invariant under temporal change of illumination) by using spatial invariant codes of the objects obtained by colour segmentation. The procedure of colour-constant processing is performed in two stages. In the first stage, a hypothesis about the dominating illuminant chromaticity is formed. This colour estimation results from the operations with tristimulus values for achromatic or glossy chromatic surface segments (Finlayson and Schaefer, 2001 *International Journal of Computer Vision* **42** 127–144; Nikolayev, 1985 *Biophysics* **30** 119–126; Tominaga and Wandell, 1989 *Journal of the Optical Society of America A* **6** 576–584). In the second stage, parameters of the reflectance spectrum for each surface segment are estimated. Input information for the algorithm at this stage consists of the estimated illuminant parameters and tristimulus (pixel) values for the test segment. The spectral power distribution function of reflected light (where the spectrum of the illuminant is also involved) and the sensitivities of photoreceptors are approximated by Gaussian functions. In such an approximation all sought spectra can be analytically recovered (Nikolayev 1985). Another advantage of Gaussian approximation is that spectral parameters (offset and dispersion) directly correspond to psychophysiological terms (hue and saturation). The algorithm is tested with both artificially generated and real images.

● **How colour-blind dichromats use basic chromatic categories: Improvements in a predictive model**

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Two models designed to predict basic chromatic categories (BCCs) used by dichromats were compared. Both models allow the following predictions: (i) specify a pseudoisochromatic line from the presented stimulus coordinates; (ii) register the intersections between that line and the BCC volumes (chromatic area and lightness). The models differed from their use in common observers in how the volume corresponding to each BCC was defined. The first one (global model) used all stimuli that consistently named a BCC to define its area (proportion of the CIE $u'v'$ diagram) and lightness range (maximum and minimum L^* values). The second one (specific model) used stimulus lightness to fix the chromatic areas corresponding to each BCC. Two populations of dichromats were used to compare the predictive capacity of the models: forty school children who named a sample of prototypes of BCC, and eight adults who named the full set of samples (1795) included in the NCS (natural colour system) atlas. In terms of the signal detection theory, both models reach a similar level of hits (ability to predict the BCC used to named the stimuli by the dichromats). However, the global model produced significantly more false alarms (it predicted BCCs that were never used to predict specific stimuli).

● **Colour constancy simulation with a multichannel neural network**

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Our aim was to examine how colours of objects depend on contrast with a background and adaptation under different illuminants and how an 'equivalent background' can be determined, and to compare the artificial neural network and its 'neurons' with the properties of single units of the visual system and its ability to discriminate colours. The neural network has up to ten input channels with three receptors, and up to ten output channels with colour opponent neurons. Several input channel configurations were investigated: (i) only two stimuli (test and background); (ii) up to ten stimulus channels and a separate background; (iii) up to ten stimulus channels and no background. The neural network was trained with signals from forty Munsell samples under various illuminants. We found that the colour constancy achieved by the neural network is good with a background signal, but poor without it. However, constancy improves if separate signals about the averaged colour of visual scenes are available. The neural network calculates colour differences between the stimuli and background. The constancy of the network, as in humans, improves with increasing variety of input stimuli. It follows that the analysis of processes in the network shows the importance of opponent mechanisms for colour constancy.

● **A neural network that implements the field model of visual interpolation**

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According to the field model of visual interpolation (FMVI) (Fantoni et al, 2001 *Perception* 30 Supplement, 20), the trajectory of interpolated contours depends on the interaction between good continuation (GC) and minimal path (MP): given a fragmented image, the chaining of GC–MP vector sums at successive locations generates an ordinate set of local tangents to the interpolation trajectory. We built a neural network that analyses an input image, extracts contours and T-junctions, and generates a series of vectorial fields: a GC field depending on the activation of units tuned to the orientation of T-junction stems; a set of MP fields depending on units activated by iteratively updated extrapolations of T-junction stems; and a set of resultant fields derived from vector sums of GC and MP fields. The interpolation trajectory is represented by the differential activation of units due to the chaining of GC–MP vector sums from T-junctions to the junction of the two extrapolations. The behaviour of the neural network has been studied with different types of fragmented images used as inputs. The simulation of vertex completion is highly compatible with psychophysical evidence. The network implements the FMVI constraints without the explicit computation of geometric measures and supports the interpolation of a wide set of input images.

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● **Face recognition with the use of principal component analysis based on artificial neural networks**

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Face recognition has been a very hot research topic in recent years and face recognition is also a high-level visual problem. The purpose of this study has been the classification of human faces by using multilayer perceptron neural networks. First, we found the feature vectors of faces by using the principal component analysis (PCA) method. PCA is one of the most successful techniques that has been used to recognise faces in images. It is a technique that extracts the orthogonal axes along which a data set varies most by computing the eigenvectors and eigenvalues of the covariance matrix of the data, which is constructed from an image database. When PCA is applied to facial images, these eigenvectors are often called eigenfaces. After obtaining feature vectors, we trained the neural network by using error-back-propagation algorithm and we used these feature vectors as an input for the artificial neural network.

● **Globally organising maximum-likelihood Hebbian learning with the use of the rectified Gaussian distribution**

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We have previously shown that maximum-likelihood Hebbian learning rules are able to find interesting structures in visual data; in particular, such rules are able to find filters of video data which are both local in time and local in space. We have also previously applied lateral connections derived from the rectified Gaussian distribution to globally organise learning (Corchado and Fyfe, 2002 *International Journal of Computational Intelligence and Applications* in press). In this paper, we combine these two ideas. We show that on a standard artificial data set (composed of a mixture of horizontal and vertical bars) the method enables clean separation of each orientation, even when the training set only contains mixtures of the two orientations. We further show that, on real video sequences, the type of filters found depends on the nature of the data set and that the lateral connections enable us to globally organise the filters found so that topographic relationships are maintained across the filters.

● **A multichannel model of depth selection.**

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A multichannel model of binocular depth selection is described. This is a subsystem of a model of human visual information transmission from retinae through lateral geniculate nuclei to the primary visual cortex. Information from the fovea and periphery of the retina is processed in different channels. We simulated the perception of halftone, colour, semitransparent random-dot

stereograms (RDSs) and RDSs of various contrasts. Our results qualitatively coincide with psychophysical data. Direct neuronal connections found in cat's visual cortex (Alexeenko et al, 2001 *Perception* **30** Supplement, 115) suggest the existence of a separate net of presumably tuned-inhibitory (TI) neurons. Our model also shows the advantages of using the TI (not excitatory) neurons in depth selection: (i) the low-frequency channel becomes sensitive to fine disparities, which is helpful for initial depth selection; and (ii) the depth discrimination is based on a physiologically significant level of an output signal. The model kernel and the experimental results are easily described by the fuzzy-sets theory. This permits the introduction of a quantitative measure of RDS discriminability and the design of stimuli with the given discriminability.

● **The stochastic retina: an edge detector in the presence of noise**

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Edge detection is the first stage in many vision systems, including biological ones. Edges are defined as local changes in contrast, and therefore gradient operators are usually used as edge extractors. However, these operators perform poorly in the presence of noise. This paper addresses the problem of a vision system observing a static scene subject to motion noise, such as vibration, jitter, or microsaccades. The system applies purely time-domain processing that extracts edges in spite of and thanks to the presence of noise. Such a system was first proposed by Prokopowicz et al (1995 *International Journal of Computer Vision* **16** 191–204) and we have formalised it as a set of stochastic differential equations. From the analysis of these equations we demonstrate that the variance of the output signal is a linear function of the local image gradient. To extract the edge information, we propose a robust, threshold-based variance estimator that is both advantageous for VLSI implementations and biologically plausible. We optimise the estimator by imposing the condition that the associated Fisher information is maximal for a well-chosen threshold. This optimisation procedure finds a natural interpretation in terms of the well-known phenomena of stochastic resonance. Numerical simulations and experiments with camera systems confirm the theoretical results.

● **Limitations of a low-level model of discrimination of change between images**

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A simple (low-level) model of local-contrast discrimination predicts object discrimination results, such as detecting subtle differences in the shape of a car, bull, or human face; this suggests that we are optimised to the second-order statistics of natural scenes (Párraga et al, 2000 *Current Biology* **10** 35–38; 1999 *Perception* **28** Supplement, 127). The model predicts discrimination thresholds given only the observer's contrast-sensitivity function. Here, we explore the limits of this model, to ask about the involvement of different (higher) visual processes.

We presented images of different sizes, either to disrupt local visual comparisons, or to alter the number of the receptors involved in the task. The results show that (a) a change in magnification between reference and test stimuli destroys the good fit of the model, except for the case of human-face stimuli which may be invariant against magnification changes, and (b) performance is similar when test/reference stimuli are either small and foveal, or are larger at 6 deg eccentricity; the model thus appears to 'M-scale'. These results support a low-level model where one particular discrimination relies on comparisons within one particular neuron set.

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● **Model of the human visual system for the evaluation of perceptual image quality of compressed images**

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Our aim was to create a model of the human visual system (HVS) suitable for evaluation of the perceptual quality of the compressed images, and to test the accuracy of the model by comparing the results predicted by it with those of the subjective image tests obtained from a group of observers. A special HVS model was developed, implemented, and tuned. The model comprises modelling of the optical part of HVS, colour separation with conversion into the CIE Lab colour space, Gaussian pyramidal decomposition, and brightness-contrast and colour-contrast processing simultaneously with masking and orientation-selective processing. The model works with

60 channels. Their outputs are weighted in order to compute a value representing the overall image quality. Evaluation of the accuracy of the model was carried out with subjective tests with a double stimulus continuous quality scale (DSCQS), conducted under standard conditions (ITU-R BT.500-6 recommendations). Perceptual image quality of images compressed by different methods and with different compression ratios was evaluated with the use of the model. The results are compared with the results of subjective tests. The excellent agreement obtained confirms suitability of the proposed model for objective image quality assessment of compressed images.

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- **Adaptive low-level vision model for feature extraction, tracking, and grouping**

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A novel neural-network model and computational theory for updating synaptic efficacy which uses cooperative recurrent inputs and feedforward retinal inputs are described. The model is motivated by the highly dynamic behaviour of receptive fields observed in cats and monkeys, and applied to low-level vision tasks including contour integration, key-point detection, and feature tracking of visual data. Also shown analytically and empirically are the importance of sub-sampling at the retina and resolution enhancement at the cortical level for reliable coding of visual inputs. The novel neural-network model described here performs such operations. The proposed computational theory also serves as a framework for fusing multiple visual features such as edges, binocular disparity, filling-in, and motion in a highly dynamic and adaptive but computationally stable manner. The intention is to incorporate the theory into existing vision models for elucidating the dynamic receptive fields of biological vision systems.

- **Basic coding mechanisms: adaptive or fixed?**

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The coding of a stimulus pattern may be conceived in terms of systems of cortical neurons with either fixed or fast-adapting receptive fields (RFs). Neurons may adapt through autonomous mechanisms, eg a (modified) Hebb rule, and/or through top-down, eg attentional, mechanisms. We present data from detection experiments with bar and sawtooth patterns, and with stimuli defined by weighted hermite polynomials (WHPs) (Yang, 1992 *Journal of the Optical Society of America A* **9** 335–336). The data from all experiments are compatible with the hypothesis of adaptive coding (Mortensen and Nachtigall, 2000 *Biological Cybernetics* **82** 410–413); those from the experiments with WHP patterns are also compatible with Yang and Reeves' hypothesis that the receptive fields of certain cortical neurons can be characterised by non-adapting WHPs (1995 *Neural Networks* **8** 669–691; *Spatial Vision* 2001, in press). However, Yang et al's simplifying assumption of low-pass pre-filtering of a stimulus (by the eye, the LGN, etc) cannot be retained: the models can only be fitted to the data if one assumes a bandpass pre-filter which adjusts (possibly by attentional focusing on parts of the stimulus spectrum) to the spectrum of the stimulus pattern, presumably to optimise the detection process.

- **Bias in nonparametric adaptive psychophysical procedures with asymmetric psychophysical functions**

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Stine (2000 *Perception* **29** Supplement, 42) showed that several nonparametric adaptive psychophysical procedures [where the stimulus that is presented on a given trial depends upon the subject's response on previous trials, and the form of the psychophysical function is assumed only to be a monotonic function of the intensity of the stimulus (see Treutwein, 1995 *Vision Research* **35** 2503–2522 for an overview of these procedures)] were essentially unbiased when sampling from symmetric psychophysical functions. Since varying guess and lapse rates or transformations of the units for the dependent variable may create skewed psychophysical functions, exploring their effects on threshold estimates is critical.

We show that each of the procedures studied previously exhibits bias with skewed psychophysical functions when used with either yes/no or two-alternative forced-choice trials. The bias varies with the specific procedure used, the initial starting conditions for each procedure, and, of course, the degree of skew in the psychophysical function. Further, even with symmetric distributions, outliers drop efficiency with some procedures suffering a larger drop than others.

READING

● Reading vertical text from a computer monitor

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Traditionally, text is presented in horizontal lines in Western languages. However, as Huey (1908 *American Journal of Psychology* 9 575–586) and Tinker (1955 *American Journal of Psychology* 68 444–449) have suggested, a vertical arrangement might be more efficient because of elimination of horizontal eye movements during reading. We investigated the effect of vertical arrangement of text on reading text presented on a computer monitor. Reading speed (words per minute) and comprehension were measured. Texts were either centred or left-aligned and words were either hyphenated or not. In the hyphenated formats there were maximally ten characters per line. Our results showed that vertical text was read 27% slower than normal text. The difference was significant at the 0.001 level. Hyphenation slowed down further the reading speed, but manipulations of text alignment had no effect. Reading speed was better in hyphenated formats than in one-word-per-line formats when speed was measured in lines per minute, suggesting that fixations per line were shorter in hyphenated formats. There were no differences in comprehension between conditions. Even though vertically arranged text was read slower than horizontally arranged text, the difference was smaller than in Tinker's study. In further studies we are going to determine whether the difference will vanish with practice.

● Reading vertical text from a computer monitor: the role of eye movements

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In Western languages, text is traditionally presented in horizontal lines. Reading such text is a well-practiced and automatic process. However, Huey (1908 *American Journal of Psychology* 9 575–586) and Tinker (1955 *American Journal of Psychology* 68 444–449) have suggested that reading vertical text might be more efficient because of elimination of horizontal eye movements. We investigated the effect of vertical arrangement of text upon reading text presented on an LCD computer display. We measured eye movements of participants reading horizontally or vertically presented text. Vertically arranged texts were either centred or left aligned, and words were either hyphenated or not. In the hyphenated formats, there were maximally ten characters per line. Analysis of eye-movement data revealed that reading text arranged in a left-aligned one-word-per-line format required fewer fixations per word than reading other text formats. Readers made fewer regressions in vertical formats than in the horizontal format. Fixation durations were shorter in the normal-text and in the one-word-per-line format than in the hyphenated formats. There might be a trade-off between fixation numbers and durations because durations were shorter for the horizontal text. The results indicate that reading vertically presented text from a computer monitor may be more efficient in terms of the number of required fixations than reading horizontal text.

● Temporal effects of stimulus changes on saccade initiation times during reading

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We investigated the chronological relationship between stimulus processing and saccade initiation in reading, using display change and manipulating the nature of stimulus before and after display change. We examined the hypothesis that completion of word processing triggers saccade, and that visual masking hampers reading by disrupting the encoding of word stimuli. The results contradicted the certain commonly adopted assumption of eye-movement control in several ways. First, frequency distributions of fixation duration indicated that inhibition on saccade initiation, rather than the delay of saccade preparation, accounts for the observed increase in mean fixation duration. Second, inhibition affects saccade programming by alternating both the latency and metrics of the immediately following saccade, with the effects emerging shortly (25–50 ms) after inhibition onset, indicating influences of inhibition on oculomotor processing. Third, visual masks containing saccade-enabling properties did not delay saccade; rather, normal saccades continued to occur until the content of the masks triggers inhibitory responses. The above evidence is best explained by Yang and McConkie's "Interaction/competition model" of eye-movement control

(Yang and McConkie, 2001 *Vision Research* **41** 3567–3585) for which saccade preparation and stimulus processing progress in parallel, and immediate cognitive influences are generated through directionally specific inhibitory signals elicited by reading difficulties.

● **Is the effect of window size on reading rate attributable to age, contrast, or content?**

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We examined whether the effect of window size (2 letters, 6 letters, no window) on reading rate could be attributed to the contrast (100% or 8%), polarity (black versus white letters), content (fiction versus nonfiction) of text, or age (14 subjects < 65 years old versus 6 subjects > 65 years old). Our results, congruent with (Florer et al, 2001 *Perception* **30** Supplement, 112), showed that reading rate increased in proportion to window size ($F_{2,36} = 611.61$, $p < 0.000001$). Both young and old subjects read significantly faster when text was at 100% contrast than at lower contrasts ($F_{3,54} = 20.79$, $p < 0.000001$). Older participants read slower than younger ($F_{1,18} = 20.12$, $p < 0.0003$). The interaction between age, window size, and contrast was not significant. Is the effect of the window size attributable to memory processes? The percentage of words recalled was not affected by window size. Contrast affected the memory of young people ($F_{3,39} = 2.9$, $p < 0.05$). Our results support the contention that the effect of window size on reading rate is attributable to the number of letters processed, and show that other visual factors, such as luminance, also affect reading rate and memory.

● **Strengthening magnocellular function by brief practice on a movement-discrimination task improved the reading speed of dyslexics, whereas no improvement was found with a word-discrimination task**

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Previous results have shown that strengthening magnocellular function by practicing left–right movement discrimination significantly improved reading fluency. The effects of practicing a 10 min computer game were compared in poor readers for two groups of children in grades 3–5. One group practiced left–right movement discrimination and the other group practiced a control game which required discriminating static words into different word categories, each for 10 min twice a week. A 2AFC method was used to measure contrast thresholds for discriminating the direction of movement and for measuring reading speed. Reading speed was measured at the beginning and at the end of this study by having the child read six words of continuous text at a time from an interesting story. After six weeks of practice, reading speed improved 54% overall for children who practiced the motion game, whereas there was no improvement (0%) overall in reading speed for children who practiced the control word game. This difference in improvement in reading speed between motion and control groups was highly significant ($p < 1.25 \times 10^{-7}$), when analysed with a z-test. Practicing direction discrimination, strengthening magnocellular function, for 10 min twice a week, provides an effective and rapid means for remediating reading problems in children.

● **Mechanisms that underlie the beneficial effect of coloured filters on reading speed**

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Coloured filters can improve the speed of reading text by a factor that varies from one individual to another but can be more than three. 5% of the school population shows substantial benefit from filters. Pre-receptoral mechanisms such as light scatter and chromatic aberration do not provide an adequate explanation. Post-receptoral mechanisms, such as the control of accommodation, cannot explain the precision of colour necessary for optimal benefit. The rods do not appear to be selectively involved, but the relative absorption of light by the three classes of cone may be more important than the colour appearance. The magnocellular deficits observed in dyslexic individuals cannot interpret the specificity of the optimal colour, or the fact that many of the individuals who benefit from filters do not have dyslexia. Instead, the findings are most readily explained by a theory of visual stress that finds support in recent imaging studies. This theory can interpret the high incidence of familial migraine in the individuals who benefit from filters when reading, and it predicts the beneficial effects of filters in the prevention of migraine attacks and attacks of photosensitive epilepsy.

THURSDAY
ORAL PRESENTATIONS**PERCEPTION AND ACTION**◆ **How is visual feedback from the hand used to control reaching movements?**

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We tested two ways that visual feedback from the hand could be used to control reaching movements. An optimal feedback controller continuously updates an estimate of the state of the hand for guiding a movement by combining feedforward predictions of state with sensory feedback. An alternative strategy simply uses the motion of the hand relative to the target as a feedback error signal. In our experiment, subjects reached to targets presented in a virtual 3-D space behind a mirror. Visual feedback was provided by a small sphere that moved with a subject's fingertip. While the hand moved behind an occluder, we perturbed the sphere in several ways: so that it emerged from behind the occluder in the wrong position, but with the same motion relative to the target (no corrections needed), in the right position but moving in a different relative motion than the hand, or in the wrong position and with a different relative motion than the hand. All perturbation conditions elicited changes in hand movement, even when they were not necessary. Corrective responses in multiple perturbation conditions appeared to be superpositions of individual responses to the position and movement perturbations. The results support an optimal control model of feedback control, and argue against the simpler, relative motion feedback model.

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◆ **Are motor effects of visual illusions caused by different mechanisms than the perceptual illusions?**

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In previous studies, we found effects of the Ebbinghaus (or Titchener) illusion on grasping. This contradicts the notion that the motor system uses visual transformations which are (a) different from the perceptual transformations and (b) unaffected by visual illusions [Milner and Goodale, 1995 *The Visual Brain in Action* (Oxford: Oxford University Press)]. Here, we tested whether the grasp effects are generated independently from the perceptual illusions. This could be the case if the motor system treated the illusion-inducing context elements as obstacles and tried to avoid them. To test this hypothesis, we varied the distance between context elements and target. Aluminum discs (31, 34, or 37 mm in diameter) were surrounded by small or large context circles (10 or 58 mm in diameter) at one of two distances (24 or 31 mm midpoint target disc to nearest point on context circles). In the perceptual task, fifty-two participants adjusted the size of a comparison stimulus to match the size of the target disc. In the grasping task, participants grasped the target disc. The trajectories were recorded and the maximum grasp apertures determined. The motor illusion responded to the variation of distance between context elements and target disc in exactly the same way as the perceptual illusion. This suggests that the same neuronal signals are responsible for the perceptual and for the motor illusion.

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◆ **Fast manual responses are not colour-blind after all**

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At the 2001 ARVO meeting we reported about an experiment that compared human responses to targets that selectively stimulate parvocellular and magnocellular neurons. It took about 40 ms longer to respond to a step displacement of an isoluminant red-green checkerboard than to a step of a flickering square (both of the same mean luminance and chromaticity as the background). We concluded that the magnocellular pathway mediates the fast responses, and proposed that the only reason that the responses to the isoluminant stimuli were still quite fast is that we had failed to completely isolate the parvocellular pathway. To check whether this is true we now masked the transients that could have stimulated the magnocellular pathway by blanking the screen for one frame before each target step. Other than this, the conditions were identical to those that we used before. The blank frame delayed responses to low-contrast luminance targets considerably. It hardly influenced responses to flickering or high-contrast targets. Most importantly, the response to isoluminant targets was not affected at all. We conclude that the parvocellular pathway can mediate fast responses, although this does take slightly longer owing to the properties of the parvocellular neurons themselves.

◆ **Oculomotor information not needed for accurate effector-relative pointing**

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Participants reproduced visually perceived horizontal extents by the amplitude of open-loop pointing actions: starting with a finger on position A, point to position B to the side of A such that perceived extent equals $B - A$. Three conditions were investigated: simple segments, segments with inner hoops, and segments with outer hoops. In the first experiment, short durations were used to prevent observers from foveating the target. Hoop-in and hoop-out movement amplitudes and times were identical. In the second experiment, segments were animated so that they appeared to expand gradually from the initial position of the finger. Participants pursued the target terminator before they pointed to it. Again, hoop-in and hoop-out movement amplitudes and times were identical. Finally, in the third experiment, displays were again presented briefly but reproduction actions were performed from a position slightly below and to the side of one of the segment terminators. In these conditions, hoop-in and hoop-out movement amplitudes and times diverged as in standard perceptual matches. These results demonstrate that similar pointing actions can be functionally dissociated under conditions that favour effector-relative versus object-relative coding of extents, and that accurate effector-relative hand transport does not require oculomotor information for target position.

[Supported by the University of Trieste.]

◆ **Allocentric perception of space and voluntary head movement**

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Although visual input depends on the position of the eye, at least some representations of space in mammals are allocentric, ie independent of the observer's vantage point or motion. Recently, such allocentric reference frames were demonstrated in human 3-D vision: by comparing the perception of structure-from-motion in actively moving and immobile subjects, we showed that extra-retinal self-motion information is used to bias towards the perception of objects that are stationary in an observer-independent or allocentric reference frame (Wexler et al, 2001 *Nature* **409** 85–88). In the current study, we asked whether the extra-retinal information responsible for this allocentric stationarity bias is due to a copy of the motor command, or to proprioceptive feedback. By comparing the visual perception of 3-D object motion in actively and passively moving human subjects, we show that the motor command contributes to the perception of space in an observer-independent reference frame: observers executing active, voluntary head movements are more likely to apply minimal-motion criteria relative to an allocentric frame of reference than are observers undergoing similar passive displacements. Furthermore, the bias towards an allocentric reference frame decreases or disappears unless the produced self-motion matches the motor command issued.

OBJECT RECOGNITION

◆ **Image-based and structure-based matching processes in object recognition**

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In recent years, some studies have suggested that there are two processes in the brain for recognising 3-D objects. In this study, the presence of the two processes was examined by a psychophysical experiment on computer-generated 3-D objects. The view that each subject recognised best was highly consistent. Therefore most subjects apparently memorised the same view as the internal representation of the objects. Furthermore, the entire reaction-time distribution could be fitted by the linear combination of Weibull distributions. According to the Bayes information criterion (BIC), the two-distribution model accounts for the data best among the three models (single-distribution, two-distribution, and three-distribution models). These results support the existence of two processes in object recognition. The temporal profile of the Weibull distribution for slower responses was dependent on the angular distance from the best view; in contrast, the temporal profile of the Weibull distribution for faster responses was not. These results suggest that the slower component might correspond to the process based on matching involving transformation of internal representation of objects based on 3-D structural information such as mental rotation, and that the early component might correspond to the process involving 2-D-image matching, whose speed of matching does not vary with view difficulty.

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◆ **Rotation and scale tuning of the recognition mechanism**

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In most cases, human ability to recognise familiar objects appears to be tolerant to scale but sensitive to orientation. Is it a genuine property of recognition mechanism or a result of matching with multiple memory representations of the same object? To address this issue, a paradigm was developed, which was a version of a paradigm developed by Lionel Standing to measure the capacity of human visual memory. At the learning stage, observers viewed 20 randomly generated patterns (4–5 Gaussian spots on a black background; 1 s presentation, 0.5 s gap). At the testing stage, observers saw a sequence of 20 pairs of patterns, one of which was familiar and the other new. The familiar pattern could be randomly rotated or scaled. The task was to choose the familiar pattern in the pair. The results from twenty-five observers show that (i) rotation does not affect observers' performance, and (ii) scaling affects the performance when the scaling factor exceeds 2. These counterintuitive results impose novel constraints on the recognition process. In particular, they suggest that to recognise an object in all scales, the visual system stores representations of several different sizes.

◆ **Adaptive bubbles**

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The 'bubbles' technique, despite its recent invention (Gosselin and Schyns, 2001 *Vision Research* **41** 2261–2271), has already proven its worth on several occasions. For example, Schyns et al (*Psychological Science* in press; see also Gosselin and Schyns, 2001 *Vision Research* **41** 2261–2271) used it to reveal the diagnostic information in three face recognition tasks; Schyns and Gosselin (in preparation) applied it to a prosopagnosic patient in a face identification task; and Bonnar et al (2002 *Perception* **31** 683–691) used it to reveal the information subtending two interpretations of an ambiguous Dali painting. In a nutshell, the 'bubbles' technique performs a non-biased search in an image-generation space (eg 2-D of spatial location in the image plane \times 1-D of spatial frequency). A major limitation of the technique is the number of trials required to reach a stable solution. Just to give you an idea: for a generation space of dimension 256×256 , it takes about 500 trials, whereas, for one of dimension $256 \times 256 \times 5$, it takes about 7500 trials. Here we present an adaptive version of the 'bubbles' technique. We used genetic algorithms [Holland, 1975 *Adaptation in Natural and Artificial Systems* (Ann Arbor, MI: University of Michigan Press); Goldberg, 1989 *Genetic Algorithms in Search, Optimization and Machine Learning* (Reading, MA: Addison-Wesley)] to achieve this feat. Early results indicate a diminution of the number of trials required to reach a stable solution in the order of 80%! Potential pitfalls of this adaptive 'bubbles' technique are discussed.

◆ **Efficiency for identifying filtered objects: looking for the template**

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An important step in understanding object recognition is isolating what information in the image our visual system uses. To tackle this problem, several studies have measured the efficiency for identifying filtered and unfiltered objects in noise. Efficiency in any given task is defined as the ratio of ideal to human threshold energy. Using rectangular bandpass filters, Gold et al (1999 *Vision Research* **39** 3537–3560) measured efficiency for identifying filtered and unfiltered letters and faces. They found that observers' efficiency for their filtered objects was always less than, or equal to, that for the unfiltered ones. We repeated their experiments using Laplacian pyramids to decompose our objects and find instead that filtering objects to particular bands of spatial frequency improves efficiency. We explain how the kind of filtering can have such dramatic effects on observers' efficiency.

◆ **Recognition of novel three-dimensional objects by summing signals from parts and views**

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Objects can be recognised despite being viewed at different orientations and distances. Two explanations of this visual ability have been proposed: one based on mentally transforming between two-dimensional object views and the other on extracting three-dimensional object parts. In an experimental test of these explanations, images of pairs of randomly generated three-dimensional objects were presented to observers who made 'same–different' judgments. Objects differed by

arbitrary rotations in three-dimensional space and in the properties of their parts so that the cue for discrimination varied along a common dimensionless scale. For long (2 s) and short (100 ms) display durations, discrimination seemed to require both parts-based and views-based processing, the two processes acting independently and additively. Under views-based processing, performance was insensitive to object structure. Under parts-based processing, performance was insensitive to view, whether the cue depended on qualitative or metric properties; and performance level increased linearly with the size of this cue. Recognition of novel, three-dimensional objects requires two complementary processing strategies that operate simultaneously, independent of the details of object structure.

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CROSS-MODAL INTERACTIONS

◆ The combination of sight and touch depends on viewing geometry

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We studied how the brain combines information from sight and touch in size perception. Contrary to earlier views that sight always dominates touch, recent evidence shows that the more visual information is corrupted by external noise, the more perceived size depends on touch. We asked whether touch information affects size perception when size is hard to measure visually. In a 2IFC procedure, each interval contained two planes. Observers indicated the interval containing the more widely separated planes. Visual stimuli were depicted with stereograms, and touch (haptic) stimuli with force-feedback devices (PHANTOMs). The planes were presented in three orientations: (i) perpendicular to the line of sight so the separation had to be judged from disparity-specified depth alone, (ii) parallel to the line of sight so the separation could be judged from 2-D separation, and (iii) 45° relative to the line of sight. Observers made size discriminations for these orientations with vision alone (V task), touch alone (T task), and with vision and touch together (VT task). In the VT task, the visual and haptic sizes were the same in one interval and differed in the other. We found that the just-discriminable separation in the V task depended on the orientation of the planes: it was significantly higher when they were perpendicular as opposed to parallel to the line of sight. Performance in the T task did not depend on orientation. Because the visual estimates varied with orientation and the touch estimates did not, optimal use of the two sources of information predicts visual dominance in the parallel orientation and more touch influence in the perpendicular orientation. Results in the VT task were very consistent with this prediction. Thus, the brain combines information from sight and touch in a way that depends on stimulus orientation. This is evidence that the weights given to sight and touch vary according to the relative reliabilities of the two information sources. [Supported by AFOSR, NSF]

◆ Using visual and haptic information for discriminating objects

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When feeling objects, vision and touch simultaneously provide information about size or shape. The purpose is to determine which representation we use for discriminating between objects which differ only in their visual and/or haptic size. We consider three representations: visual alone, haptic alone, and combined visual–haptic. Integrating the information optimally, the combined visual–haptic percept is a weighted average of the two sizes. To measure discrimination performance, subjects indicated the odd of three sequentially presented stimuli. These were horizontal bars, two of which were identical and had equal visual and haptic heights (standard). The third (odd) stimulus had a different visual and/or haptic height. If subjects used the visual-alone or haptic-alone representations, discrimination would occur whenever the visual or haptic height in the odd stimulus differed from the standard by more than the threshold. If subjects relied on the combined representation, no discrimination should occur when visual and haptic heights differ in opposite directions, so that their weighted averages are equal and discrimination should be best when both these heights are either bigger or smaller than the standard. We found that discrimination was indeed most difficult when the weighted averages were equal. Thus, the combined visual–haptic percept is used for discrimination. However, if the conflict between visual and haptic heights became too large, discrimination improved, indicating that we also can access the visual-alone and haptic-alone representations.

◆ The integration of auditory and visual motion signals

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There is evidence that visual and auditory signals are integrated at a perceptual level (eg Meyer and Wuerger, 2001 *NeuroReport* **12** 2557–2560) and in spatial-attention tasks. In this study we investigated (i) whether the integration of visual and auditory motion signals depends on the direction of the motion signals in the two modalities, and (ii) at what processing level the integration occurs. The visual stimulus consisted of a random-dot kinematogram. The auditory stimulus consisted of a noise pedestal which was different for each loudspeaker and an incremental noise component that was cross-faded between the two loudspeakers, giving rise to a motion percept. Auditory and visual motion directions could either be consistent (both to the left or both to the right), or inconsistent (one to the left, the other to the right). The task of the observer was to detect the motion signal irrespective of direction and modality. We find that motion detection thresholds for inconsistent and consistent motion are very similar and are well fitted with a probability-summation model; subthreshold summation does not account for the data. These results suggest that the integration of auditory and visual motion signals occurs at a rather late processing stage and is not selective for the direction of the movement.

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◆ Visual weight in audiovisual integration is task-dependent

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As visual and auditory systems have specific spatial-processing mechanisms, the question arises of audiovisual spatial resolution. Assuming that the relative weight of each sensory modality to perception of a bimodal stimulus depends both on the spatial sensitivity of each elementary sensory system and on the task goal, spatial resolution was compared in a fusion task (forced-choice between co-located or spatially disparate sources) and in a localisation task (motor tracking to superimpose a cross marker on the perceived location of an auditory stimulus, a visual one, or an assumed unique bimodal event). Stimuli were a 2 deg visual spot and a broadband noise displayed over an 80 deg H × 60 deg V field; they were strictly synchronous in the bimodal condition. The shape and extent of the fusion areas varied directly in relation with auditory characteristics in term of spatial resolution. The relative location of each modal component also revealed the dominating contribution of the broad spatial tolerance of audition. These results concur towards audition playing an essential role in visual–auditory fusion tasks. Nevertheless, in a localisation task, the spatial resolution of the visual modality drove the accuracy of the bimodal responses. The effective signal in a bimodal stimulation varies depending on the goal pursued by perception.

◆ Testing the unique internal representation across the visual and auditory modalities

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We have shown that in visual detection (Gorea and Sagi, 2000 *Proceedings of the National Academy of Sciences of the USA* **97** 12380–12384; 2002 *Visual Cognition* in press) and discrimination (Gorea and Sagi, 2001 *Nature Neuroscience* **4** 1146–1150) tasks where two signals are presented with equal probabilities, observers use a unique decision criterion in accordance with a model whereby their decisions are based on a unique internal representation (Gorea and Sagi 2000). Here we test this model across visual (V) and auditory (A) domains. Depending on the colour of a visual post-cue, subjects had to report the presence/absence of an 80 ms contrast or loudness increment of, respectively, a 3 cycles deg⁻¹ – 40% Gabor, or a pure 1000 Hz – 80 dB tone. A-increments and V-increments were presented either in separate blocks (modal conditions), or simultaneously with independent probabilities of 0.5 (intermodal conditions) and chosen to yield *d'* values around 1 and 3. The criteria assessed in the intermodal conditions were quite similar to those measured in the modal conditions, pointing to independent visual and auditory internal representations. Also, intermodal *d'*s were significantly lower than modal *d'*s and decreased in proportion with the sensitivity of the paired stimulus, pointing to a failure in attending both modalities simultaneously. These results suggest that sensory information is represented modally and that it cannot be attended independently across modalities.

NATURAL IMAGES

◆ Spatiochromatic information in natural scenes

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To what extent does colour vision match the properties of natural scenes? Chromatic mechanisms are relatively more sensitive to low spatial frequencies than luminance mechanisms. Perhaps this reflects some general property of natural scenes, but empirical evidence argues against this. However, since there is separate evidence that colour vision evolved for frugivory, we asked whether the properties of scenes of fruit and foliage differ from those of general scenes. The results suggested that such scenes are indeed optimally signalled by primate spatiochromatic vision, but only for the red–green system (Párraga et al, 2002 *Current Biology* 12 483–487). What about the yellow–blue system? Its spatial properties are similar to that of the red–green system. However, we have found no spatial optimisation for foliage encoding. The problem with this system is that shadows are bluer than highlights, and are therefore not removed from dappled scenes. The only situation in which there is evidence of spatial optimality is when patches of blue sky are visible through the leaf canopy. Thus, spatial encoding by the yellow–blue system may be optimised for distinguishing between foliage and sky, or perhaps for an entirely different, yet undiscovered, class of tasks.

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◆ Predicting the response of retinal ganglion cells to natural stimuli

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The use of natural stimuli in visual neuroscience has been met with great enthusiasm by some. Others have argued that, although different at first glance from a mechanistic point of view, they are no more than a sum of spatiotemporal sinusoids. We investigated to what extent the responses of cat retinal ganglion cells to natural movies can be predicted from their spatio-temporal filter characteristics. We measured linear receptive-field properties of single retinal ganglion cells with luminance-contrast ‘checkerboard’ stimuli in a reverse correlation paradigm. The reverse correlogram was used to predict the cells’ response to natural movies. Results show that, although the reverse correlation function provides a fair estimate, substantial deviations from the measured response remain. We find that predictions for the response to drifting sine-wave gratings are considerably more accurate, provided that physiological properties, such as signal rectification and adaptive processes, which are underrepresented in the reverse correlogram, are taken into account. We find that, even after such corrections, predictions for natural stimuli deviate considerably from the measured response. The origin for these deviations may reside in additional nonlinearities, such as refractoriness of the spike generator.

◆ 1/f channel reweighting predicts many aspects of lightness perception

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We describe a model of human visual processing of lightness that uses biologically plausible receptive fields combined with a novel form of channel recombination. Images are decomposed into a series of spatial-frequency bands (by a bank of centre–surround filters) and then reconstructed by using a $1/f^z$ weighted sum of a restricted subset of the higher-frequency filters. Although this process adequately reconstructs natural images, it can also drastically reduce the disruptive effect of gross luminance variation on their component features. We go on to show that it also provides a unified account of the presence and magnitude of a wide range of illusions including simultaneous brightness contrast, brightness induction, White’s effect, grating induction, various transparency illusions due to Adelson, the Chevreul illusion, Mach bands, and Craik–Cornsweet edges.

◆ Multi-scale structure of visual figure and ground in Japanese dry landscape gardens

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Japanese dry landscape gardens show interesting visual effects, especially where rich visual designs are presented as perceptually calming environments. Drawing on visual psychology, we use the concept of ‘figure–ground’ relationships to investigate the appeal of some gardens.

A 'figure' of rocks and bushes is typically placed on an empty 'ground' of gravel. We show that texture patterns and grouping arrangements between visual cues are repeated and balanced at multiple spatial scales, qualifying as a naturalistic design. The structure of visual 'ground' is not so readily apparent and the analysis benefits from a quantitative approach. Computed perceptual sensitivity maps (Kovacs and Julesz, 1994 *Nature* **370** 644–646), equivalent to medial axes, reveal the structure of empty expanses between rocks in the famous Ryoanji garden. Medial axis loci have numerous unexpected non-accidental properties that are destroyed with random perturbation of the original design. The analysis leads to a novel interpretation of structure in the 'ground' of this garden design. The structure of the 'empty space' in some other famous dry landscape gardens is found to be similar to that at Ryoanji, with some interesting variations on a common theme. This suggests that designers of traditional Japanese gardens possessed sophisticated intuitive understanding of, and control over, subtle visual effects. Our findings provide directions toward the design of more naturalistic, calming visual environments.

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◆ **Rapid categorisation of natural scenes: feedforward vs feedback contribution evaluated by backward masking**

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Humans and monkeys can categorise briefly flashed natural scenes so fast that rapid feedforward mechanisms probably play an important role. To test this possibility explicitly, we analysed the effect of a strong dynamic pattern mask at varying stimulus onset asynchronies (SOAs) in our standard go/no-go categorisation task. Subjects had to respond as fast and accurately as possible each time there was an animal in monochrome natural scenes flashed for only one frame with a vertical refresh rate of 160 Hz. With a 6.25 ms SOA, the masking effect was virtually total. But performance rapidly improved as SOA was increased by 6.25 ms steps, and was well over chance for an 18.75 ms SOA. At these very short SOAs, the analysis of simultaneously recorded event-related potentials showed that differential activity between targets and distractors was present, and that its amplitude was correlated with behavioural performance; however, subjects had little or no conscious perception of the target, relying more on something akin to blindsight. Such results fit with recent suggestions that a rapid feedforward pass may allow access to high-level object representation, and trigger behavioural responses, but that activation of conscious awareness may require time-consuming processes involving recurrent feedback pathways (Lamme and Roelfsema, 2000 *Trends in Neurosciences* **23** 571–579).

COMPLEX MOTION

◆ **Stereoscopic motion standstill: phenomenon and theory**

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Motion standstill is an unusual perceptual phenomenon in which an observer perceives a rapidly moving pattern as being motionless and yet its details are not blurred but clearly visible. We created reliable motion standstill in dynamic random-dot stereograms (DRDS), as first reported by Julesz and Payne (1968 *Vision Research* **8** 433–444), by making three major improvements in their paradigm: (i) motion temporal frequency is manipulated independently of stereo temporal frequency so that the failure of motion perception at high frequencies is not due to stereo failure; (ii) instead of back-and-forth motion between overlapping stimuli, stimuli move continuously across the field so that the motion standstill percept is not the result of averaging successive flashes; (iii) objective psychophysical methods (rather than introspection) are used to demonstrate failure of motion perception concurrent with the survival of good pattern vision. We observed robust stereoscopic motion standstill at 4–6 Hz, which matches with the temporal cutoff frequency of the third-order motion system. Motion perception in our DRDS motion display is computed only by the third-order motion system. When this motion system fails, it reveals the function of the pattern system in isolation. The pattern system combines similar, rapidly succeeding frames (snapshots) into a single representative percept.

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◆ **Modelling curvature polarity in multi-stable 3-D structure from motion**

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Recently we found that leftward and rightward moving dots with sinusoidal speed profiles elicit four spontaneously alternating structure-from-motion percepts. Observers not only perceived the well-documented clockwise and counterclockwise spinning cylinders but also either two convex or (less frequently) two concave half-cylinders. Here we model these data. The inputs consist of leftward and rightward moving dot patterns with speed profiles that induce curvature in depth. On the basis of the principle of 'common fate' we assume that the leftward and rightward moving patterns are processed separately. The curvature polarity (convex or concave) of each pattern is the result of local polarity averaging. Both positive and negative curvatures are equally probable at each iteration. The stability of the modelled percept is achieved through temporal averaging where longer temporal averaging windows reduce the average frequency of percept changes. The curvature polarity of the percept is the polarity which occurred most frequently over previous iterations. After the curvature of both the leftward and rightward moving patterns have been determined they are combined to form (half-)cylinders. In conclusion, a simple model, which can easily be implemented by connectionist networks, can explain the occurrence of four spontaneously alternating structure-from-motion percepts. The stability results from temporal averaging over unstable, random, inputs.

◆ **Optical snow and the aperture problem**

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When an observer moves in a cluttered 3-D scene such as a forest, the image motion that results is complicated by the fact that multiple objects are present near each image position. These multiple objects produce a dense motion parallax effect, resulting in multiple image velocities near each image position. An extreme example of this type of motion is what an observer sees during a snowfall. For this reason, we have referred to image motion in a cluttered 3-D scene as 'optical snow'. Human observers and other seeing animals, such as flying birds, are able to visually navigate through cluttered 3-D scenes, which suggests that there exist simple biological mechanisms for processing optical snow. In earlier work, we presented a computational model for recovering the direction and range of image velocities present near each image point, by a mechanism akin to distributed representations of motion energy detectors. In the present study, we investigate the aperture problem, which arises in optical snow when the spatial structure in the scene is dominated by one direction such as the predominantly vertical structure in a forest. We show how to express the aperture problem using a spatiotemporal frequency analysis, and we relate the aperture problem in optical snow to the classical case of the aperture problem that arises in optical flow. We also offer a new set of optical snow stimuli that can be used both in computational modelling and in human psychophysics.

◆ **Direction asymmetries for incidentally processed walking figures**

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Recently we have begun to explore the incidental processing of biological motion. We ask whether walking figures that an observer is told to ignore still affect performance on a primary task. Using a number of different paradigms, we have shown that to-be-ignored walkers are still processed and can affect behaviour. During the course of these studies we have observed that such incidental effects are often modulated by the left-right orientation of the ignored walkers. More specifically, the extent of interference tends to be much larger when the to-be-ignored figures are shown in left profile versus right profile. Furthermore, the magnitude of the asymmetry tends to be much larger when the primary task itself is attentionally demanding. Here, we present data from two paradigms, an Eriksen flanker task and a novel 'checkerboard' task. In the latter, alternate display squares contain either a walking figure or a patch of randomly moving dots. Observers are told to ignore the walkers and have to make judgments on the relative phase of the dot patterns. Data from both tasks are used to illustrate the aforementioned direction asymmetry and the results are discussed in terms of canonical viewpoints for attentional sprites.

◆ **Aftereffects in biological motion perception**

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The human visual system shows an impressive sensitivity to subtleties in animate motion patterns carrying biologically relevant information. Frontal views of biological motion point-light walkers can be classified with respect to the gender of the walker with high accuracy. Here, we document pronounced adaptation effects that alter the perceived gender of a point-light walker. Stimuli were generated by a morphing technique which provides smooth transitions between male and female walking patterns. Observers were first presented with five walking cycles of either an exaggerated male walker, an exaggerated female walker, or a neutral walker. Subsequently, they were tested with 700 ms presentations of walkers sampled along the male–female walking axis. Their task was to indicate whether the test walker was a man or a woman. A psychometric function was fitted to the data. Adaptation to the male walker results in a pronounced shift of perceived gender of the test stimulus. A neutral walker is perceived to be female after adaptation with the exaggerated male walker, and male after adaptation with the exaggerated female walker. This demonstrates that adaptation can occur not only within low-level vision processes but also at high-level information-processing stages.

PERCEPTUAL ORGANISATION

◆ **Dynamics of modal and amodal completion**

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Many models of modal and amodal completion assume that the two phenomena are based on the same underlying principles, the only factor differentiating the two being the relative depth of the interpolated contour (Grossberg and Mingolla, 1985 *Psychological Review* **92** 173–211; Kellman and Shipley, 1991 *Cognitive Psychology* **23** 141–221). However, psychophysical evidence is equivocal. Ringach and Shapley (1996 *Vision Research* **36** 3037–3050) and Gegenfurtner et al (1997 *Perception* **26** 1445–1458) found that the exposure time had to be significantly longer for amodally than for modally completed contours to achieve the same level of performance in a shape-discrimination or localisation task. They interpreted the difference in dynamics between modal and amodal completion as reflecting differences in the processing of local features in the two cases, rather than differences in contour completion per se. Here, we compared shape-discrimination performance for modal and amodal completion in novel configurations equated for local geometry, manipulating mode of completion by adjusting the luminance of inducing segments. We found significantly better shape-discrimination performance in configurations favouring modal completion, demonstrating that the difference in the dynamics between modal and amodal completion persists when structure and local features are controlled for.

◆ **Contour polarity and visual interpolation**

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Contour polarity (ie concavity/convexity of bounded regions) is a determinant of shape perception [Bertamini, 2001 *Perception* **30** 1295–1310; Kanizsa and Gerbino, 1976 *Vision and Artifact* Ed. M Henle (New York: Springer) pp 25–32; Koenderink, 1984 *Perception* **13** 321–330]. However, current interpolation models do not consider it among factors modulating the sharpness of interpolated angles. At the level of contours, the field model of interpolation predicts trajectories as an interaction of minimal path and good continuation [Fantoni and Gerbino, 2001 *Journal of Vision* **1**(3) 461a]. At the level of surfaces, two opposite hypotheses can be formulated: (i) avoidance of concavity: the tendency to minimise the concavity implies a decrease in the sharpness of the interpolation trajectory of concave angles; (ii) minimal area: the tendency to minimise the figural area implies an increase in the sharpness of the interpolation trajectory of concave angles.

We demonstrated, using a probe localisation technique, that contour polarity affects the completion of 90° angles. We compared four types of displays, obtained by combining contour polarity of the occluded form and shape regularity. Observers judged the position of a brief probe, superposed on the occluder, relative to the amodally completed contour. Results support the minimal-area hypothesis. Independently of the regularity of the occluded form, the probe was localised closer to the good continuation solution when the occluded vertex was concave than when it was convex.

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◆ Sensitivity for global shape detection

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Early stages of visual processing sample shapes by discrete, localised visual filters. Information is then integrated by neurons that extract shape. Using a global shape task, we investigated what limits the performance of the mechanisms that detect shape. In a 2AFC task, subjects judged which of two arrays of Gabors contained global circular structure. We varied the signal-to-noise ratio to measure coherence thresholds. The stimulus was composed of randomly positioned and oriented Gabor patches. In the target, some elements were coherently oriented tangential to the circumference of circles centred in the middle. Thresholds were obtained for arrays of different area, density, and number of elements. Thresholds were also obtained for Gabor elements of different carrier spatial frequencies, contrasts, and with positional and orientational jittering. Global structure was detected when $\sim 10\%$ of the elements were coherently oriented. Neither the properties within the array (density, area, number or position of elements) nor those of the individual elements (contrast or spatial frequency) altered sensitivity. Varying contrast or carrier spatial frequency within individual arrays also did not alter performance. Only jittering the local orientation of elements decreased sensitivity. Detecting circular structure is a robust process that is mainly limited by local orientation information.

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◆ Psychophysical evidence of cortical dynamics in contour integration

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We determined the effect of element separation on the dynamics of contour integration. The task requires the linking of orientation across space to detect a path, measured by a temporal 2AFC method of constant stimuli. Gabor patches ($1.5 \text{ cycles deg}^{-1}$, $\sigma = \lambda/4$) were randomly positioned within a 10×10 square grid with typically 10 elements forming a path. A stimulus cycle consists of a path or no-path stimulus followed by a masking stimulus with random orientation of its individual elements. The path and no-path stimuli were presented cyclically for 1 s modulated by a temporal Gaussian window. We measured the effect of the temporal orientation modulation of the individual elements as a function of temporal frequency (1–38 Hz), curvature (0° – 30°), and element separation (2λ – 5λ). Our results reveal that the temporal resolution of contour integration: (i) decreases with element separation; (ii) decreases with path curvature at all element separations; and (iii) is better for long straight paths (10 elements) than for short straight paths (5 elements) or closed paths, with the largest difference at the shortest element separation. These findings extend our previous results (Hess et al, 2001 *Vision Research* **41** 1023–1037; Beaudot and Mullen, 2001 *Perception* **30** 833–853) on the curvature-dependent dynamics of contour integration, and bring new insights into the involvement of feedforward, intracortical, and interareal feedback processing in contour integration.

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◆ The detection of smooth curves in jagged contours

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Jagged contours with sharp edges, such as those formed by the fractal edge of the Mandelbrot set, have a lower correlation in position and shape between different scales than smooth curves. The more jagged the contour, the lower the correlation. In principle, coarse changes in position of a curve, be it jagged or smooth, can be coded by using operators tuned to low-luminance spatial frequencies; but, to code the fine changes in position of a jagged contour, small operators are required. Since a sharp-luminance-transition contour is visible to both high-spatial-frequency-tuned and low-spatial-frequency-tuned operators, the question arises whether coarse changes in shape are coded via low-spatial-frequency-tuned cells, or via high-spatial-frequency-tuned cells whose outputs are pooled by a coarse-scale higher-order mechanism. We investigated this issue by conducting two experiments. In the first experiment, we show that shape-amplitude detection thresholds of a sinusoidal contour increase with the blur of the contour, and that the threshold functions are parallel over a large range of shape spatial frequencies, implying that high-(luminance)-spatial-frequency-tuned mechanisms that are more shape-and-position sensitive come into play whenever they can be supported. In the second

experiment, we measured the threshold for shape-amplitude detection of a low-shape-frequency sinusoidal contour in the presence of shape harmonics of various amplitudes, for both (luminance) spatial-frequency unfiltered, and high-pass spatial-frequency filtered, contours. We found no difference in thresholds for shape-amplitude detection when using filtered and unfiltered stimuli. We conclude that coarse shape information is coded with the smallest operators available. In the context of a model of vision that emphasises the role of self-similar 'filters' tuned in spatial frequency, our results are consistent with the idea that contour shape is encoded via high-spatial-frequency-tuned cells, possibly of the highest spatial frequency capable of responding to the contour. [Supported by URC (Hong Kong) and NSERC (Canada).]

POSTER SESSION

BINOCULAR VISION

● Orientation disparity and the perception of surface slant

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It has been suggested that the perceptual impression of slant can result from the operation of mechanisms that are sensitive to orientation disparities between the retinal images. We have estimated the threshold for dichoptic rotation necessary to induce surface slant for stimuli that have been constructed from bandpass-filtered visual noise. Increasing the orientation bandwidth causes a large drop both in monocular and in binocular orientation acuity owing to increases in the stimulus orientation uncertainty. However, changes in orientation bandwidth have no impact on the orientation acuity for creating slant in depth, strongly suggesting that orientation-tuned mechanisms are not involved in this task. We found also that orientation thresholds for inducing slant rise substantially when the stimuli are superimposed on a pedestal of static disparity of position, which would not be predicted to have any impact on the operation of a mechanism that was sensitive solely to a disparity in the orientation domain. We conclude that perceived slant results from relatively conventional processing of the positional disparities that are inevitably created by an underlying disparity of orientation, and that for spatially extended stimuli, as used here, it is not necessary to invoke the existence of higher-order mechanisms.

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● Modelling interactions between chromatic and achromatic stereopsis mechanisms

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Despite a number of demonstrations to the contrary, there is still debate over the existence of a chromatic-contrast-sensitive stereopsis mechanism. Whilst recent studies have focused on the presence or absence of luminance artifacts at nominal equiluminance (eg Champion and Simmons, 2001 *Perception* 30 Supplement, 81) there is still the question whether or not such a mechanism is necessary in order to adequately explain performance away from equiluminance. Earlier we (Simmons and Kingdom, 1998 *Perception* 27 Supplement, 21) presented stereoacuity data obtained with $0.5 \text{ cycle deg}^{-1}$ Gabor stimuli which possessed different relative amounts of (red-green) chromatic and luminance contrast. These stimulus components could be correlated or anticorrelated between the eyes. We have since found that an adequate explanation of these data requires the evocation of three independent stereopsis mechanisms: first-order luminance, first-order chromatic, and second-order luminance. These mechanisms interact via probability summation of depth sign information before the extraction of stereoscopic depth. The formalism developed to model these data, based as it is on a four-parameter fit to contrast-dependence data obtained with each component contrast separately, has interesting implications for modelling other aspects of the contrast dependence of stereoscopic judgments with complex stimuli.

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● Vertical-disparity pooling across spatially segregated surfaces

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Vertical disparities contribute to scaling of size and depth only with sufficiently large fields of view, which suggest that their use for small objects is limited (Bradshaw et al, 1995 *Vision Research* 36 1255-1264). We investigated the possibility that this might be overcome if information from

different surfaces could be pooled over three-dimensional space. Observers adjusted the size and shape of a virtual, binocularly defined ellipsoid to match those of a real, hand-held tennis ball. The virtual ellipsoid was presented at four distances (30, 40, 50, and 60 cm) in four conditions: (i) alone; (ii) surrounded by a frontoparallel frame at a distance of 46 cm; no information was presented in a $23.2^\circ \times 24.4^\circ$ deg rectangle surrounding the ball; (iii) manipulated vertical disparities in the frame simulated a distance of 26 cm; or (iv) 66 cm. In all conditions, perceived size and shape varied with distance. Settings were not influenced by the presence of the surround. Manipulation of vertical disparity in the surround to simulate a closer viewing distance influenced the perceived shape (but not size) of the ball, consistent with the use of a smaller estimate of distance to scale disparities. Vertical-disparity pooling thus alters the perceived shape of objects, even for surfaces that are clearly spatially segregated.

● **The resolution of binocular correspondence by vertical disparity interpolation**

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The binocular correspondence for an oblique line is ambiguous when its endpoints are occluded. This is a stereoscopic aperture problem caused by uncertainty about the disparity component parallel to the line orientation. We show that the aperture problem in stereo does not occur when unambiguous information about the gaze angle of the fixation point is available, and we present a theory of binocular correspondence that establishes a unique match of lines by utilising the gaze information from vertical disparities. The theory predicts that, when surrounded by an expansion/contraction disparity field, parallel lines in the frontal plane will be displaced on to the plane which is tilted toward an orthogonal direction to the orientation of lines; moreover, the slant of the plane will increase in proportion to the cosecant of the angle of orientation of the lines with respect to horizontal. This prediction was tested and confirmed in a psychophysical experiment. The result suggests the existence of a mechanism that interpolates vertical disparities to find the matching solution of lines in an otherwise featureless space.

● **Binocular interactions in human visual cortex: evidence from fMRI**

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Using functional magnetic resonance imaging (fMRI), we explored the binocular interactions occurring when subjects viewed dichoptically presented checkerboard stimuli. A flickering radial checkerboard was presented to each eye of the subject, while T2*-weighted images were acquired over visual cortex with a gradient-echo, echo planar sequence. We compared responses in striate and extrastriate visual cortex under four conditions: both eyes were stimulated at the same time (binocular condition), each eye stimulated in alternation (monocular condition), or first the one eye then the other eye stimulated (left eye first – right eye trailing, or vice versa). The results indicate that only the striate area, in and near the calcarine fissure shows significant differences for these stimulation conditions. These differences are not evident in more remote extrastriate or associational visual areas, although the BOLD response in the stimulation-rest comparison was robust. These results suggest that the effect could be related to inhibitory interactions across ocular dominance columns in striate visual cortex.

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● **Illusory surface is not necessary for depth asymmetric stereo capture**

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In stereo capture a disparate Kanizsa square pulls background texture bounded by the illusory contours to the same depth plane as the illusory square (Ramachandran and Cavanagh, 1985 *Nature* 317 527 – 530). The perceived phenomenon is depth-asymmetric, ie the near and far figures are perceived qualitatively differently. Because the depth asymmetry is similar in stereo capture and in stereoscopic illusory surface formation (Blomfield, 1973 *Nature – New Biology* 245 256 – 257), it has been suggested that the same process mediates stereo capture and illusory surface formation. However, we demonstrate that the depth asymmetry is present even without a disparate illusory surface. We used periodic dot textures as inducing figures and tested the stereo capture both in

near and far directions. The results show that the inducing figures captured the texture to near direction normally, but did not capture the dots to far direction. Thus, an illusory inducing figure is not required for the depth-asymmetric stereo capture. We suggest that the capture is affected by local interactions among the texture dots during the capture process. These interactions include contour ownership processing, which determines the direction of rematching spreading during capture, and half-occlusion processing that determines the shape of the captured surface.

● **Interocular transfer of second-order tilt aftereffects**

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Previous work has established that the tilt aftereffect transfers in part between stimuli defined by first-order cues (luminance differences) and by second-order cues (differences in the direction of random-dot motion, or illusory lines defined by line endings). This suggests the existence of shared mechanisms which respond to more than one type of cue. However, the location of these mechanisms is unknown.

Here, we therefore examine the interocular transfer of the tilt aftereffect as a function of type of contour. After adapting one eye to contours tilted 15° from vertical, subjects set test contours (of the same type), seen through the same or the other eye, to apparent vertical. With contours defined by luminance (narrow bright bars on a dark screen) or by motion (random dots moving in opposite directions in alternating bands), interocular transfer was partial ($<100\%$). However, with illusory contours defined by line endings, or with contours defined by differences in texture (stochasticity of dots), transfer was almost complete. We conclude that some (but not all) kinds of second-order contour are processed within purely binocular channels.

● **The effect of image blurring degree, luminance, and chromatic contrast in one eye on stereovision**

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The main goal of this investigation was a study of the stereovision threshold when the stimulus in one eye undergoes blurring, or when it loses intensity or colour contrast. In our experiments we used red–blue (R/B) and black–white (B/W) random-dot pairs of stereostimuli generated on a PC screen. Stimuli presented to the right eye and the left eye were separated: (a) haploscopically, with prisms; (b) with blue and red filters; and (c) by phase separation, with liquid-crystal shutters that were synchronised with the display frame rate. Two ways of stimulus imbalance were applied: optical blur, and B/W and R/B colour contrast change in the stimulus presented to one eye. The sequence of blurring images was generated according to the continuous Gaussian distribution (FFT analysis and cross-correlation were used as an objective measure of blur in parallel with the subjects' 'vision acuity', and testing against the Landolt C chart with the same degree of blurring). The subjects' task was to mark when they lost and regained stereopsis. In order to study the effect of contrast of the stimuli presented to one eye on stereoacuity, the B/W and R/B contrast of the stimuli presented to the dominant or nondominant eye was continuously changed—either uniformly or more in the centre than in the peripheral area according to the Gaussian distribution. The stereovision acuity decreased with the change of colour contrast and with blurring intensity. The minimal contrast level needed for depth perception was $6\%–8\%$ for R/B colours, and $2\%–6\%$ for B/W if contrast in the stimulus presented to the other eye was held at 100% . But the actual values depended on the size and type of disparity.

● **Changes in tonic accommodation and vergence after immersion in a virtual-reality environment**

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The aim of this experiment was to establish the effect of virtual-reality (VR) stimulation upon the tonic elements of the accommodation and vergence controllers. Twenty emmetropic subjects (mean age 22.0 ± 4.5 years) participated in the experiment. Tonic accommodation (TA) was measured in darkness with the Shin-Nippon SRW-5000 infrared autorefractor. Tonic vergence (TV) was measured with an Eyetrace 300× infrared limbal eye-tracker. Subjects were then immersed in a VR environment for 30 min, generated with SimulEyes field-sequential shutter goggles controlled by a Dell XPS R450 PC. Following immersion, measurements of TA and TV were repeated. Mean pre-task TV was 1.89 ± 3.30 metre angles (MA). The TV became significantly ($p < 0.005$) more divergent as a result of the VR stimulation (mean change 3.58 ± 5.26 MA).

Pre-task TA (0.41 ± 0.73 D) was not significantly different from post-task TA (0.34 ± 0.70 D). We found that the VR environment produced substantial adaptation of TV in the divergent direction. There are no significant changes in TA in the VR environment. These findings suggest that the initial reaction of the accommodation and vergence controllers is to shift vergence bias in order to minimise the stimulus conflicts found in VR environments. This enables subjects to maintain a stable accommodation response despite continual changes in the vergence position. [SS is supported by The Carnegie Trust for the Universities of Scotland.]

- **Nulling of stereomotion induction and reverse stereomotion suppression**

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We have established stereomotion induction, ie motion induction in the stereodomain (Likova and Tyler, 2001 *Perception* Supplement, 78). Here we further explore the stereomotion induction process by (i) a cancellation technique, and (ii) extending the cancellation motion into the zone beyond the nulling point. The stimuli were dynamic autostereograms consisting of a target and a surround; both were horizontal lines of discs. The stereomoving surround induced depth motion into the stationary, unchanged in disparity, target. Adding actual stereomotion to the target cancelled the induced motion experience when it was in the opposite direction. Increasing the cancellation motion to the nulling point surprisingly decreased not only the induced target motion, but also the stereomotion in the surround. Beyond the nulling point, perceived motion in the target increased, while the surround-stereomotion perception was almost suppressed in a wide range of disparity changes. We named this novel phenomenon of suppression of the stereomoving surround by stereomoving target 'reversed stereomotion suppression', in contrast to the process of attributing stereomotion from the surround into the stationary target during 'straight' induction. A model of the target/surround interactions has been developed and is discussed in the context of dynamic organisation principles, operating in stereomotion perception and misperception.

- **Sampling of binocular-disparity information and human stereoacuity**

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We examined the factors that limit the ability to resolve surface corrugations from stereopsis. Using a haploscope, we presented observers with disparity-modulated gratings. The orientation of corrugations in the image plane deviated from the horizontal by $\pm 20^\circ$. The disparity modulations were applied to random dots, regular grids of dots, and Delaunay meshes. We measured stereoacuity by asking observers to discriminate between the two orientations of corrugations, while the spatial frequency of modulation was varied according to an adaptive staircase. In contrast to previous claims, we found that human performance depends strongly on dot density. To elucidate the cause of this improvement, and to understand how the positioning of disparity information on surfaces affects stereoacuity, we explored the following properties of disparity placement: (i) the optimality of dot placement (dots positioned randomly versus aligned with the peaks and troughs of disparity modulation); (ii) element connectivity (isolated dots versus linear and curvilinear meshes); (iii) dot homogeneity in the image plane (dots distributed uniformly versus clustered, preserving the overall dot density); (iv) dot homogeneity in depth (disparities spread uniformly across depth versus confined to a few disparity values). We find that each of these manipulations affects stereoacuity.

- **Accommodation responses in observation of pan-focus stereoscopic images**

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When observing pan-focus stereoscopic images, eye accommodation might focus to the distance of vergence without mismatch between accommodation and vergence, since the focal depth of the pan-focus image is too deep. Our object in this study was to examine how stereoscopic image position guides eye accommodation. Deep focal depth condition (D) such as pan-focus, and shallow focal depth condition (S) were set as stereopsis focal depths. The target was an aerial image with an image plane made to float in space by means of an optical system. Real image condition (R) and old stereoscopic image condition (O) were compared with conditions D and S, respectively. Under conditions D, S, and O, the image plane was set 100 cm from the subject's eyes. Subjects observed radial-pattern targets for 3 s set at four distances from the subject's eyes by

binocular disparity. Under conditions D and R, the accommodation distance was shorter as the target position approached the subjects. Under conditions S and O, the accommodation distance did not change even though the target position was close to the subjects. These results indicate that accommodation is guided to the target position by vergence induced by binocular disparity in the observation of pan-focus stereoscopic images.

● **Visual perception of impossible geometries: local and global constraints in stereopsis**

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The first step in stereopsis is stereo-matching, where the brain searches for corresponding features in the images on the two retinas. The locations of corresponding features depend on the visual scene and on the orientations of the eyes, so, theoretically, the brain could use information about eye position, derived from motor or proprioceptive signals or from the retinal images themselves, to guide stereo-matching. If it does, then stereopsis should be confused by random-dot stereograms of impossible scenes that violate the rules relating eye position and retinal correspondence. We presented subjects with stereograms in which different parts of the images implied different eye positions. When the contradictory parts were spatially segregated, stereopsis was normal: subjects simultaneously perceived stereo shapes in both parts. When the contradictory parts were superimposed so that every region of the image contained inconsistent data, stereopsis was impaired relative to controls using superimposed but consistent stereograms. It appears that the brain does not use motor, proprioceptive, or visual information about eye position to constrain stereo-matching globally, over the whole image, but it may calculate multiple local estimates of eye position based on the images in small patches of retina and use these estimates to guide stereo-matching in those small regions.

[Supported by CIHR and DAAD.]

● **Age dynamics of binocular integration in children**

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We investigated the capability of children to combine incomplete left and right visual images into a single integrated percept in dichoptic viewing conditions by the anaglyphic method to separate the left and right test stimuli. In total, about one hundred and fifty subjects were tested: two groups of pre-school children (with normal vision and with binocular disorders), two groups of junior school children (1st and 3rd form), and a control group of adult subjects (students). Test stimuli were 10 simplified letter-like configurations divided into left and right fragments and exposed briefly (50–800 ms). To evaluate improvement of binocular integration with age, the curves representing probability of stimulus recognition as a function of its duration were obtained for each subject not only in dichoptic conditions but also in monocular conditions when both stimulus fragments were presented to one and the same eye. The results of monocular experiments were used to separate maturation of binocular mechanisms from maturation of the relevant cognitive mechanisms that had to contribute equally to the results obtained in all conditions. The data obtained show that, in children with normal binocular vision, the rate of binocular integration increases with age rapidly and reaches the adult level at about 9 years.

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● **Right angle in binocular vision**

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We measured the accuracy with which subjects judged 90° angles following binocular fusion. Three bright dots, 1 min of arc diameter each, formed an image of an angle with the two sides 30 min of arc long. The reference image was shown to the right eye or the left eye of the subject, and the test image to the opposite eye. When presented, the two patterns fused together into a single stimulus consisting of three dots arranged to form an angle. In the experiments, the subject varied the angle of the test image in 1° steps by moving the end-dots of the pattern with the panel keys. The subject's task was to place the end-dots into a position in which the whole stimulus appeared to be a right angle. Within the interval 75°–105°, the subjects were highly successful in performing the task, and adjusted regularly the test angle, being somewhat symmetric according to the reference angle, eg when the reference was 80° or 95°, the test was adjusted to 100° or 85°, respectively. Such a result fits into the simple law of arithmetic mean and can be discussed in terms of the right-angle phenomenon, and the stimulus symmetry effect.

● **Stereoscopic matching and the aperture problem**

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In order to perceive stereoscopic depth, the visual system must define binocular disparities. Consider an oblique line behind an aperture. Because the line is perceived behind the aperture, the line must have disparity relative to the aperture. What is the relationship between perceived depth and the assigned disparity of the line in this aperture problem? One theory is that “horizontal disparity is not a reliable cue to depth” and that “aperture disparities” determine the perceived depth (Farell, 1998 *Nature* **395** 689–693). A reply to this theory states that horizontal disparity determines depth, independently of the aperture orientation (Anderson, 1999 *Nature* **401** 342–343). However, no objective measurements have been conducted to resolve the theoretical discrepancy. Here five observers adjusted the horizontal disparity of a probe until it was perceived at the same depth as the disparate line behind the aperture. The results show that, in order to perceive the probe at the same depth as the line, the probe must have the same horizontal disparity as the line (more precisely, matching occurred along a horizontal search zone). Results are largely independent of the aperture orientation. We conclude that horizontal disparity is a reliable signal for determining depth when apertures are present.

ILLUSIONS

● **Reverse perspective and the effects of visual-field reversals**

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The ‘reverse-perspective’ illusion entails the apparent motion of a stationary scene painted in relief and containing misleading depth cues. We found that when we used prism goggles to induce horizontal or vertical visual-field reversals, the illusory motion disappeared in the direction for which the goggles reversed the visual field. This was found in two separate experiments with prism goggles that reverse the visual field both left–right and top–bottom. We argue that the illusion is a consequence of the observer’s inability to reconcile changes in visual information due to body movement with implicit knowledge concerning anticipated changes. As such, the reverse-perspective illusion may prove to be useful in the study of the integration of visual and proprioceptive information.

● **Mach bands change asymmetrically during solar eclipses**

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Shadows cast by objects in full sunlight exhibit Mach bands: strips of light and dark not physically present in the shadows but visible at their edges. During a partial eclipse of the sun in Perth, Western Australia, it was noted that Mach bands became asymmetrical. First, bright Mach bands disappeared on shadows on the right-hand side of objects but not on the left; later in the eclipse, positions were reversed. Why? As the moon ‘swallows the sun’, it breaks down its symmetry, leaving crescents that are mirror-symmetric about a single axis. This changes the luminance profiles and the symmetry of left and right shadows. Changes in the Mach bands seen during eclipses are consistent with a local-energy explanation of them as features whose appearance depends on their spatial phase (see Morrone et al, 1986 *Nature* **324** 250–253).

● **Symmetrical angular figures constrain the perpendicular bias in childrens’ line copying**

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It is well established that when young children copy a vertical line that protrudes from the midpoint of an oblique baseline, they perpendicularise the vertical line relative to the baseline. Here, we measured this perpendicular bias for standard figures (baseline 8 cm, testline 4 cm) and for symmetrical angular figures (each leg 4 cm). Children (mean age 6 years) copied single testlines (4 cm). The baseline or, for angular figures, one leg of the figure was predrawn. The veridical orientation of the testline and predrawn line was 0° (horizontal), 180°, 45°, and 135°. For all figures the angle between the two lines was 45°. The results show a perpendicular bias for the standard 8 cm–4 cm figure. However, for angular figures these large errors were not found. For example, for one type of figure, a vertical line on an oblique baseline gives a 10° bias, the angular version only 2°. This result generalises across all orientations. We conclude that the perpendicular bias results when two lines are perceived as separate. In contrast, angular figures are processed as shapes and this limits large local orientation interactions.

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● **Three-dimensional surface and two-dimensional contour**

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Hitherto, the usual approach to two-dimensional geometrical illusions has been based on the study of local information of the stimulus figure, eg differences of brightness between the contour and its surrounding. But it is not necessarily the properties of the contour lines themselves that underlie the illusion, but the character of the surrounding may be the main factor. I demonstrated earlier (2001 *Perception* 30 Supplement, 77) that the diameter of a three-dimensional random-dot hemisphere was perceived to be smaller than that of a two-dimensional dotted circle. This result indicates that the perceived size of a circle is determined not only by the circular contour lines but also by the spatial depth character of the surrounding. Here, using the motion parallax of moving random dots, I formed the three-dimensional surface of a hemisphere. As the perception of depth of a rotating hemisphere is more familiar than that of an immobile stereo pattern, I obtained a more pronounced shrinkage. As W Metzger said, "three-dimensionality of our visual world is an intrinsic phenomenon". Thus, all geometrical illusion figures drawn two-dimensionally are perceptually only special states of a more general three-dimensional situation, and their explanation must be based on the general principle of three-dimensional space, eg formation of a three-dimensional surface.

● **The influence of colour on the scintillating grid illusion**

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The scintillating-grid illusion is a brightness-contrast phenomenon in which small white disks are added at the intersections of a gray-on-black Hermann grid. With each flick of the eye, flashing dark illusory spots are perceived within the disks (Schrauf et al, 1995 *Perception* 24 Supplement, 88–89; 1997 *Vision Research* 37 1033–1038). We investigated whether these illusory spots were affected through coloured grids. As equiluminous coloured grids produced no illusory spots [Schrauf et al, 1998 *Tübinger Wahrnehmungskongferenz* Eds H H Bülhoff et al (Kirchentellingfurth, Germany: Knirsch)], luminance differences were kept maximal between the grid elements (dark background, lines of medium luminance, bright disks). Three configurations were tested: (a) grids with coloured background and gray lines, (b) grids with black background and coloured lines, (c) grids with complementary colour of lines and background. Every grid induced scintillating coloured illusory spots. These illusion colours were matched in terms of saturation and hue. Illusion colours were found to be always desaturated and either of the same hue as the background [(a) and (c)] or of the complementary hue to the lines [(b)]. Results indicate the involvement of two different mechanisms underlying these coloured illusory sensations: whereas background colours induce the same hue (colour assimilation mechanisms), the colour of the lines induce colours of complementary hue (colour contrast mechanisms).

● **Computation times for binocular depth perception: A psychophysical analysis of the 'delayed stereopsis illusion' (DSI)**

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Viewed pseudoscopically, an opaque square floating above a random-dot pattern appears as a rectangular cut-out. When the pattern moves upwards, an illusory gap is perceived at the upper edge of the square. In analogy with Julesz's 'no-man's-land' we called this DSI-gap 'trailing-edge no-man's-land'. Its width, marked by subjects under well-defined conditions, indicates the 3-D computation time needed to determine spatial depth of the pattern, which virtually appears 'from nowhere'. Early data suggested that in 3-D vision there are two different processing pathways for fast and slow movements [as Gegenfurtner et al (1996 *Trends in Neurosciences* 19 394–401) found in normal motion analysis]. Learning, and parameters like spatial frequency, disparity between the square and the moving pattern, and brightness within the range of photopic vision did not significantly influence the perceived width of the DSI-gap. In scotopic vision, however, it was increased in accordance with the Pulfrich effect.

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● **The effect of binocular fusion on perceived length distortions**

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Static and variable Müller-Lyer figures were shown separately to different eyes of the observer. The figures had no shaft lines. The two parts of the static figure and the reference part of the variable figure were identical in length, but the test part of the variable figure varied. Irrespective of length differences, the two figures fused together into a single Müller-Lyer pattern, and the observers adjusted the test part of the variable figure via the computer keyboard to obtain length equality in the fused pattern. The illusion strength was measured as a function of the length of the reference part and the size of the wing angle. Qualitatively, the functions obtained were similar to those seen in monocular measurements (Bulatov and Bertulis, 1997 *Biological Cybernetics* 77 395–406). The quantitative data on both functions showed that, following binocular image fusion, the strength of the Müller-Lyer illusion was twice that observed with monocular or binocular presentations of a single illusory figure. The experimental results obtained fit in with Hering's law: the visual direction of a fused image which falls on slightly disparate retinal points is the average of the two visual directions.

● **Misperceptions in the peripheral representation of curvature**

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When a circular object is viewed centrally initially, its curvature is veridically represented by the visual system. However, when an identical circular form is presented peripherally for the same period of time, it appears polygonal in shape. In the present study we measured the induction time of this misperception, and quantified the number of sides of the misperceived circular form. For a circle of fixed radius (2 deg), or scaled to compensate for cortical magnification, the induction time of the illusion reduces linearly with increasing retinal eccentricity—a 1 deg shift in eccentricity resulting in a reduction in the induction time of approximately 13%. We quantified the number of sides of the distorted image by presenting the illusion followed by a variable polygonal probe presented centrally. Observers indicated whether the peripheral illusion had greater or fewer sides than the probe using a staircase procedure. When the circular target is peripherally scaled, the number of sides remains constant at approximately 7 sides ($N = 5$). However, a fixed-size circle (2 deg) appears to have fewer sides with increasing eccentricity, approximately 5 sides at 8 deg eccentricity ($N = 5$). We discuss the implications of this illusion with respect to the ability of peripheral visual mechanisms to faithfully represent curved contours. [Supported by the Australian Research Council. PVM is supported by the Wellcome Trust.]

● **Illusory jitter induced by flickering surround texture: effects of flicker frequency and duty cycle**
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I have previously reported a new motion illusion (Murakami, 2002, Vision ScienceS, Abstract 2 254): a static random-dot pattern (within a disk-shaped region) that is surrounded by a synchronously flickering random-dot pattern (within a concentric annulus) appears to move in random directions, as if mimicking small eye movements of fixation. Several observations have confirmed that this illusory motion actually reflects one's own fixational eye movements that are normally unnoticed. By using the matching method, the magnitude of this apparent jitter was measured as a function of flicker frequency and so-called duty cycle (the fraction of time during which the surrounding pattern is displayed for each cycle of flicker). First, it was found that the illusion was most pronounced when the frequency was 4.7–9.4 Hz. Second, the optimal duty cycle for the illusion was 75% on-duty, irrespective of frequency. I propose that given the same retinal-image slip in the disk and annulus, the flicker with its frequency and duty cycle at these optimal values elicits most noisy directional responses, degrading velocity estimation in the annulus. A subsequent process for retinal-image-slip compensation may use these artificially weakened signals as a frame of reference, resulting in undercompensation for velocity in the disk.

● **A novel reverse-motion illusion from contrast modulation**

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A drifting grating that is contrast modulated over time produces an illusory percept of motion in the opposite direction. The illusory motion occurs around the minimum contrast such that the overall percept is reminiscent of a ratchet; the grating seems to move to and fro during the high-contrast and near-zero-contrast temporal phases, respectively. The illusion has several

interesting features. It is unlike traditional motion adaptation in that the illusion becomes salient very quickly (within two or three temporal cycles and is apparent only at low spatial frequencies). The illusion cannot be explained by feature or phase mismatching across temporal cycles for at least two reasons. First, it persists if random noise stimuli are used and changed across temporal cycles. Second, the spatial extent of the illusory motion is roughly constant across grating spatial frequency. Results from dichoptic alternation of successive contrast-modulation cycles are consistent with a central origin of the effect. A model using OFF and ON channels captures some aspects of the illusion but not others. Spatially interleaved static noise that is also contrast modulated over time influences the illusion as a function of relative temporal phase, indicating a possible role for a gain-control mechanism.

● **Transformational apparent motion is blind to optical illusions**

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We aimed to investigate the anatomical/functional level of shape distortion induced by optical illusions. Specifically, we wished to determine whether the illusion exerts its effect at the level of position encoding or at a later stage where the more abstract and global form information is derived. The extraction of both form and motion involves the computation of position information. If the optical illusion exerts its effect at the level of V1 where the most accurate position is available, the induced shape change should affect both form and motion perception. If, on the other hand, the shape distortion occurs at a later stage, the motion system could be immune to optical illusions. We used Hering's illusion to create perceptually bent lines, and tested if these lines could drive the motion system to produce transformational apparent motion. The results showed that the motion system is blind to the illusion, indicating that the optical illusion does not take its effect at any stage common to form and motion systems.

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● **A new Hermann-grid variant: scintillating dots, spurious lines, neon-colour spreading, vacillating and pulsating motion**

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Small white disks, superimposed on the intersections of a grey-on-black Hermann grid, are known to evoke dark illusory spots within the disks as flashing with each flick of the eye (scintillating-grid illusion). Here we show that additional amazing phenomena can result from selective removal of the white disks (from 3×2 stripes with 3 adjacent crossings out of a matrix with 23×16 crossings). The disk-free area emerges, owing to neon-like colour spreading, as a super-grid surface (with 6 crossings); it further contains 3 thin spurious lines (diagonally to the Hermann grid and darker than the background). On longer inspection, the spurious lines appear to vacillate; finally pulsating motion is seen within the whole striped area. These effects depend on viewing distance and luminance level, and are strongest with diagonally oriented Hermann grids (respectively orthogonal super-grid surface) and blue backgrounds. Spatial filtering shows oblique Fourier components that can account for the spurious lines, first described by Prandtl in 1927, and dark spots, but not for scintillation and the pulsating dynamics; these might rely on the modulating activity of slow hyperpolarising potentials of 'configural units' in cortical area V4 (Wilson et al, 2000 *Nature Neuroscience* 3 170–176).

● **An anomalous motion illusion based upon signal delay**

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We found a new anomalous motion illusion, which looks like the Ouchi illusion but is different in the direction of illusory motion. In the Ouchi illusion, we see an illusory motion in a direction perpendicular to a retinal slip, whereas the direction of this new illusion is the same as the retinal slip. In a series of experiments, we ascertained lightness contrast to be the critical factor. Low-contrast random dots showed longer signal delays than high-contrast ones, irrespective of their average luminance or contrast polarity. Within low-contrast patterns, 'dark' ones showed longer delays than 'light' ones. This illusion can be regarded as an extension of the Hess effect, which is characterised by signal delays shown by low-contrast, 'dark' patterns. Since the Hess effect is known as the monocular manifestation of the Pulfrich effect, we examined whether illusory motion in depth could be observed when low-contrast and high-contrast 'light' patterns were binocularly fused and moved horizontally. Under these conditions, observers rarely reported illusory motion in depth. Possible explanations of this discrepancy are discussed.

VISUAL IMPAIRMENTS AND CLINICAL

● The representation of global spatial structure in amblyopia

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In visual space it is often necessary to integrate information over an extended area to determine a useful global percept. Amblyopia is characterised by distorted representations of global spatial form, thought to be caused by increased internal noise or reduced sampling efficiency. It is possible that the visual mechanism by which local stimulus attributes are integrated into a global percept is poor in amblyopia. The purpose of this study was to quantify such perceptual distortions by means of an orientation discrimination and an interocular matching task. Stimuli were composed of pseudo-random arrays of highly visible and resolvable Gabor patches whose local orientation and position were systematically varied. Observers were required to discriminate whether the mean orientation of the elements was tilted to the right or left of vertical, as a function of orientational and positional variability. In control experiments the contrast of individual elements and the number of elements present were also varied. Observers also matched the spatial distribution dichoptically with identical stimuli. Orientation discrimination thresholds and interocular matching in the amblyopic eye showed increased levels of variance for orientation and position. It would appear that amblyopes are able to integrate orientation information across visual space, but the global representation of local structure shows greater variability compared to normal. It is this increased local spatial uncertainty that underlies the spatial deficit in amblyopia.

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● Dynamics of impairments of working-memory processes on a model of Alzheimer's disease in monkeys

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We have investigated the characteristics of visual working memory in a delayed-discrimination task model of Alzheimer's disease (AD) in rhesus monkeys. Three animals received unilateral stereotaxic intracerebroventricular injection of the nucleus basalis of Meynert (nbM) and locus ceruleus (lc) lesioning agents. The remaining three monkeys received sterile saline injections and thus served as controls. The lesioning agents consisted of a ribosomal toxin, saporin, conjugated to monoclonal antibodies against (the nbM lesion) the p75 neurotrophin receptor (p75NTR) and against (the lc lesion) the enzyme dopamine b-hydroxylase (DBH). The monkeys were trained to discriminate stimuli with different types of visual information. The data obtained demonstrate that the nbM and lc lesioning agents had a weak effect on visual differentiation without delay (long-term memory), but significantly decreased the duration of information storage in working memory two months after the injection. These changes depended on the stage after injection and stimulus properties, and were accompanied by an increase of motor reaction time and of refusal of task decision. In monkeys that were sham injected, there were no alterations in working-memory characteristics. These results suggest that degradation of cholinergic structures, which begins on this stage of AD model, is expressed in neural structures of cortical areas.

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● Free-space stimulation improves blur accommodation responses in late-onset myopia

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Our purpose was to determine whether free-space and binocular stimulation would improve the quality of accommodation responses in subjects with late-onset myopia (LOM). Ten emmetropic subjects (mean age 22.3 ± 2.3 years) and ten LOM subjects (mean age 21.8 ± 1.5 years) participated in the study. A specially modified Canon R-1 infrared optometer was used to measure accommodation responses under three conditions: (a) monocular blur-only stimulus; (b) monocular free-space stimulus; and (c) binocular free-space stimulus. We found that accommodation microfluctuations were significantly ($p < 0.01$) smaller in magnitude in the LOM group with the free-space stimulus. There was a significant ($p < 0.01$) increase in the percentage of correct step accommodation responses to the free-space stimulus in the LOM group. Step response times in the LOM group with the free-space stimulus were not significantly different than those found with the blur-only stimulus, and were significantly ($p < 0.01$) longer than those found in the emmetropic group. Binocular stimulation produced no significant improvements in accommodation response in the LOM group. It is concluded that: (i) static accommodation responses are significantly

improved in LOM subjects with free-space stimulation; (ii) the quality of dynamic accommodation responses in LOM subjects improves significantly with free-space stimulation; and (iii) LOM subjects appear to rely upon proximity-driven stimuli for accommodative accuracy.

● **Reaction time in myopes—faster than in emmetropes?**

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By selectively blocking the ON-system, Schiller et al (1986 *Nature* **322** 824–825) found that, in rhesus monkey, longer times are required for the discrimination of shape, colour, flicker, movement, and stereo images. On the other hand Stoimenova et al [1995 *Vision Research* **35**(4) S79, A1434] showed that myopes had a higher sensitivity to ON- than to OFF-stimulation, especially at mesopic luminance levels. The above observations supply grounds to assume that visual reaction time may be shorter in myopes as compared to emmetropes. We tested the above hypothesis on a limited number of subjects with low to moderate degrees of myopia using the paradigm of forced-choice reaction time. The results showed that the myopes in our group have indeed a significantly shorter visual reaction time as compared to a matched group of emmetropes. These results support the earlier observation of Hiltz et al [1978 *Proceedings of ICO-11 Conference, Madrid, 1978* (Madrid: Instituto de Óptica 'Daza de Valdes' CSIC and Sociedad Española de Óptica)] for a supernormal temporal visual capacity in myopes.

● **Objective blur threshold for ocular accommodation in emmetropia and late-onset myopia**

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Our purpose was to determine the magnitude of the objective blur threshold for ocular accommodation in emmetropia and late-onset myopia (LOM). Six emmetropic subjects (mean age 19.3 ± 2.3 years) and six LOM subjects (mean age 20.2 ± 1.5 years) participated in the study. All subjects were fully corrected with soft contact lenses (Acuvue). A specially modified Canon R-1 infrared optometer was used to measure continuous accommodation responses to a high-contrast letter target in a Badal system. Sinusoidal stimuli with amplitudes of 0.1, 0.2, 0.3, and 0.4 D were presented randomly at 0.6 Hz.

Accommodative responsiveness increased with the amplitude of the stimulus at a significantly ($p = 0.01$) faster rate in the emmetropic group. The minimum objective blur threshold was significantly ($p = 0.01$) greater in the LOM group (0.4 D) than the emmetropic group (0.1 D). We conclude that (i) the objective blur threshold for ocular accommodation in the emmetropic group is smaller than reported values of subjective ocular depth of focus; (ii) the LOM subjects exhibit reduced accommodative responsiveness and an increased objective blur threshold compared to the emmetropic group; and (iii) this indicates that previously reported increases in subjective ocular depth of focus in LOM subjects are reflected in the magnitude of the objective blur threshold for accommodation.

● **The influence of spatial distribution on computations of peak absorbance and the total amount of macular pigment**

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To determine the influence of variable spatial distribution on computations of total and peak macular pigment (MP) we measured the MP distribution profiles of seventeen subjects with a Moreland anomaloscope modified for motion photometry. Each profile was determined by computing absorbance at different retinal locations relative to a reference value obtained between 5 deg and 7 deg eccentricity. The total amount of MP in the central 7 deg was estimated from the distribution profile. This was done by fitting a 3rd-order polynomial to the data for fine scale interpolation and assuming radial symmetry for numerical integration. Additionally, MP was assessed in eight of the subjects by means of fundus autofluorescence imaging. The shape and lateral extent of MP distribution was found to vary between subjects and these variations could not be predicted from peak absorbance alone. Reducing the reference location to 4 deg or 2 deg eccentricity resulted in underestimation of peak absorbance by up to 40% and 80%, respectively. There was a four-fold difference in computed total MP for peak absorbance values between 0.4 and 0.5, in subjects demonstrating a high degree of MP radial symmetry according to fundus autofluorescence imaging. We conclude that the distribution of macular pigment is an important

variable when estimating total MP. Accurate psychophysical assessment requires the use of reference locations, which lie beyond significant macular pigmentation.

[A G Robson is supported by the Foundation Fighting Blindness.]

● **Assessments of macular pigment density and distribution by motion photometry and fundus autofluorescence**

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Our object was to determine whether fundus autofluorescence imaging can assess the distribution and total amount of human macular pigment (MP). For this purpose MP distribution profiles were measured for eight subjects with a Moreland anomaloscope modified for motion photometry. Fundus autofluorescence images were obtained from the same subjects with a scanning laser ophthalmoscope. Optical density profiles, derived from grey-scale values of autofluorescence images, were compared with those derived by motion photometry.

Localised discontinuities in the autofluorescence MP profiles, corresponding with retinal blood vessels, were discounted in analysis. Autofluorescence images showed radial symmetry across the nasal, temporal, superior, and inferior meridians, within $\pm 8\%$. MP profiles, derived from the two techniques, were closely correlated ($r = 0.95$) but the autofluorescence data required a scalar multiplier of about 2.5. We conclude that MP distributions, in autofluorescence images, show radial symmetry and correlate closely with those deduced from motion photometry. Autofluorescence imaging provides a fast noninvasive method for assessing MP in vivo.

[A G Robson is supported by the Foundation Fighting Blindness.]

● **Looking at one's own cone cells: entoptic structures visualised through a moving pinhole or a microscope with excentrically rotating aperture stop**

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When looking at a bright white surface through a 0.5 mm pinhole quickly moved close to one's eye on a circular path, the shadows of 'mouches volantes' are flitting too fast across the retina to be detected. Instead, shadows of those structures are perceived which are close above the photosensitive layer: capillaries surrounding the foveola, and between them 'leather-like structures' [v. Campenhausen, 1993 *Die Sinne des Menschen* (Stuttgart: Thieme) p.110] consisting of tiny bright dots. We determined their spatial frequency psychophysically by comparing it with that of a small flock of painted dots. When viewed through the excentrically rotated pinhole, both spatial frequencies are perceived simultaneously and they appear equal from a well-defined distance. Thus, on the retina the dots must be about 15 μm apart, which coincides with the size of cone cells. We hypothesise that the dot pattern represents the 'shadows' of the cone cells' nuclei, each of which operates as a tiny ball lens, owing to its higher refractive index. When looking through a microscope with an excentrically rotating aperture stop, this dot pattern is seen all over the bright field, since the image-forming cone of rays steadily hits the retina from different directions. In ophthalmology, this pattern may serve to diagnose the beginning of a degeneration of one's own macula.

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● **Dyslexics show poor efficiency in detection and discrimination visual tasks**

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Studies on normal observers have identified two factors that limit the visibility of simple patterns: internal noise and sampling efficiency. Some dyslexics report that letters appear distorted and move when reading small or densely packed print. The poor visual performance of dyslexics with such print could be accounted for by either an increase in the level of the internal noise within the visual system, a decrease of the efficiency with which dyslexics encode task-relevant information, or both.

We applied the equivalent noise approach in conjunction with a 2AFC method to measure internal noise and sampling efficiency in two visual tasks: (i) detection of a flickering 2 deg patch

to stimulate the magnocellular pathway and a motionless 5 cycles deg^{-1} grating to stimulate the parvocellular pathway, and (ii) discrimination of a letter presented individually or within a three-letter string. Internal noise was found to be similar in all observers tested regardless of the visual task. Dyslexics showed significantly poorer efficiency for all stimuli. Some authors have postulated that dyslexics have an impairment of the magnocellular pathway, but our results reveal that the poor visual performance of dyslexics is not specific to the stimulated visual pathway. Instead we suggest that dyslexics use the available information inefficiently.

- **Strange beasts: sensory, structural, or semantic?**

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Patient PHD has a category-specific visual agnosia characterised by impaired recognition of animals and relatively spared recognition of objects. His understanding of animal names was relatively preserved. His sensitivity to the perceptual structure of animals that he was unable to name, match, or define from visual input was explored by using a chimera judgment task. PHD was unable to discriminate real from composite animals, but had no problem in differentiating real from composite objects. Mixed animal-object chimeras were trivially easy for him. These effects were found across a range of different grades of task difficulty and visual complexity. In a second experiment, he was more likely to retain information about real than composite animals in a delayed copying task. These findings indicate that PHD's category-specific problem cannot be attributed to a 'low-level' visual impairment but is more plausibly explained in terms of selective loss of the structural descriptions of living things or their visual semantic representations. [The support of the Wellcome Trust is gratefully acknowledged.]

- **Pathological completion: mindsight?**

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Islands of blindness (scotomata) caused by damage to the visual regions of the brain may be accompanied by the subjective experience of completion of forms that should be occluded by the visual defect, a symptom termed 'pathological visual completion'. We report a single case whose experience of completion was systematically influenced by changes in the stimulus display. His disorder could not be explained by residual vision or an attentional disorder. Pattern masking, varying the contrast characteristics of stimuli, and changing visible cues to structural symmetry all had precise effects, whereas familiarity and structural coherence did not. We suggest that pathological completion may be a positive cognitive event implicating processes that underpin the normal experience of occluded forms.

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- **How do unseen stimuli feel? Covert processing of emotional valence in a blindsight subject**

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Blindsight is the capacity of patients with visual field defects from retro-geniculate lesions to respond to visual stimuli they do not consciously see. Although numerous residual visual functions (localisation, detection, and discrimination of features, including motion, size, spatial frequency, and wavelength) have been demonstrated, comparatively little is known about the processing of the emotional valence of the unseen stimuli. We used 33 coloured emotional images, subtending $10 \text{ deg} \times 10 \text{ deg}$ and presented with their centre 8 deg off fixation. They were presented singly for 1 s in the visual field defect while fixation was monitored with an eye-tracking system. The patient's task was to decide, without time limit, whether the stimulus was 'pleasant' or 'unpleasant', and to rate her confidence in her response on a scale of 1–3. In the first testing session, her hit rate was 76.9%, in the second 61.3%. In addition, her confidence rating was higher on average for correct responses. These results underpin the assumption that the affective valence of unseen visual stimuli can be processed even in the absence of visual awareness, and suggest a possible involvement of limbic structures in the mediation of blindsight.

- **Visual evoked potentials in early multiple sclerosis**

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Early multiple sclerosis (MS) is a condition with various manifestations. The mistakes in its diagnosis reach 30%–40%. Paraclinical methods, measured nerve-impulse velocity in visual pathways, such as visual evoked potentials (VEPs), are of great importance. Therefore we have tried to find specific electrophysiological VEP markers of subclinical demyelination in MS. Nineteen

MS patients, 13–43 years old, were tested. Clinically definite (1st group), probable (2nd group) MS according to C M Poser (1983), and healthy control groups consisted of eleven, eight, and twenty subjects. Six of eight patients in probable MS had clinical features of acute disseminated encephalomyelitis. Every person was presented a chequers reversal pattern with spatial frequencies (SFs) of 0.61, 1.21, 2.43, and 4.85 cycles deg^{-1} . On evaluating N1, N2, P1, P2 components we found decreasing amplitude in all SFs in all MS patients compared to controls: N2 and P2 latency in 1.21 cycles deg^{-1} , SF and N1 latency in 2.43 cycles deg^{-1} ; SFs were increased in the 1st group compared to the 2nd group. The established differences of latency may be used for correct diagnosis of early MS and other inflammatory diseases of the central nervous system.

- **Multiple sclerosis patients: MRI localisation and VEPs to checkerboard patterns in noise**
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We compared VEPs and the primary brain deficit localised by anatomical MRI in patients with multiple sclerosis (MS). Pattern reversal VEPs to checkerboard patterns presented on a uniform background or on a noise background were recorded in normal subjects and in patients. We used seven contrasts (0.01–0.64) of checkerboard patterns with and without noise (0.0012–0.64 contrasts). Peak-to-peak amplitude and latencies of the main VEP components were analysed. On the uniform background, latencies of the main VEP components were significantly higher in patients with MS than in normal subjects at all contrasts used. This delay might be evidence of abnormal signal processing in these patients' visual systems. Almost all patients showed a decrease in the amplitudes of responses to stimuli at all contrast values. For normal subjects, additive external noise increased the latencies P1, N2, and decreased N1P1, N2P2 to stimuli with contrasts 0.0025–0.32 in noise background of contrasts 0.005–0.64. At main contrasts, the additive external noise did not significantly change the latencies and amplitudes in MS patients. The internal noise level in MS patients is higher than in normal subjects. We compare this with localisation.

- **Dyschromatopsia in cases of multiple sclerosis**
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The visual function deficit in optic neuritis and multiple sclerosis results from the effects of demyelination and axonal loss in the optic nerve. We sought to characterise the dyschromatopsia in persons with multiple sclerosis, to determine the type and severity of colour defect and its relation to the stage of disease. A computerised Farnsworth–Munsell 100 (FM 100) hue test was used. Colour-vision test data in sixty-three persons with multiple sclerosis and ninety controls were analysed. We used quantitative analysis of FM 100 test error scores to determine the severity, the selectivity, and the type of dyschromatopsia. There was no significant correlation between the visual acuity and the FM 100 hue test total error score ($r = 0.32$) and between the FM 100 hue test total error score and the changes in the fundus of the eye ($r = 0.41$). Persons with all stages of multiple sclerosis showed significantly worse total error scores on FM 100 hue test than controls ($p < 0.001$). Red–green defects (8% of cases) were more frequent than blue–yellow defects. This can be regarded as a confirmation of the applicability of Köllner's rule of colour perception to persons with multiple sclerosis.

- **Colour vision in persons with optic-nerve atrophy**
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A computerised Farnsworth–Munsell 100 (FM 100) hue colour-vision test was used to test two groups of observers: fifty with optic-nerve atrophy of various origins and ninety controls. Their ages ranged between 21 and 50 years. The testing was performed monocularly. For each of the two groups, we calculated total error scores as well as the red–green and blue–yellow selective error scores, using the FM 100 hue test (Smith et al, 1985 *American Journal of Ophthalmology* **100** 176–182). All of the statistics were calculated from the square root of the total and selective error scores. The data showed significantly worse performance on the FM 100 hue test by observers with optic-nerve atrophy ($p < 0.001$). The changes of the red–green selective scores in observers with optic-nerve atrophy were almost identical to the changes of the blue–yellow selective error scores. There was no significant correlation between the FM 100 hue test total error scores and the vision acuity scores ($r = 0.47$).

● **Dependence of visual acuity on observation distance in 5–10 year-old children**

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Recent accurate measurements of visual acuity at various viewing distances in young adults (Heron et al, 1995 *Ophthalmic and Physiological Optics* **15** 23–30) and in school children (Rozhkova et al, 2001 *Sensornye Sistemy* **15** 257–263) have revealed that cases of acuity changes with distance are more frequent than cases of its constancy. This means that dependence of visual acuity on distance is a rule but not an exception or an anomaly as was thought earlier. In order to clarify the physiological basis of this dependence, we examined about two hundred children aged 5–10 years with normal far and near visual acuity (not less than 1.0 in decimal units) trying to exclude the influence of possible degradation of accommodation ability with age. Uncorrected binocular and monocular visual acuity was measured for single E-type stimuli (in four orientations) at five viewing distances in the range 0.5 m–5.0 m. We found that, even at pre-school age, most children demonstrate better acuity at intermediate distances like most school children and adults. Typical differences between visual acuity values obtained for the optimal and the extreme distances were of 0.4 decimal units. Only about 10% of children had visual acuity that was independent of distance. To explain the existence of optimal observation distances in most children even at pre-school age, a number of developmental and environmental factors could be proposed that adjust the parameters of the visual system to the parameters of operational visual space and prevailing activity. [Supported by the Russian Foundation for Basic Research, grant 01-04-49484.]

● **Achromatic contrast perceived by people with colour perception alterations: using the AMLA method to avoid non-differentiable figure – ground combinations in conventional screens**

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Three experiments related to the AMLA method are described. This method was designed to predict the lightness of stimuli presented by computer screens. AMLA can be used with observers with and without colour perception disturbances. AMLA has two stages. In the first (achromatic measurement), a standard luxometer is used to measure the relative luminance of achromatic stimuli (their value in comparison with white luminance). The first experiment showed that four measurements are enough to accurately compute the exponent gamma value. To infer the luminance of each chromatic stimulus, the second stage of AMLA uses a psychophysical technique that identifies an achromatic stimulus with luminance similar to the one of the target chromatic stimuli. One psychophysical technique based on spatial acuity was compared with another based on temporal acuity in experiments 2 and 3. With common observers ($N = 20$), both techniques were similar to standard photometric measurements, excluding the fact that the spatial technique tended to underestimate blue primary luminance. Experiment 2 showed that five protanopes made the expected adjustments in people lacking the cone more sensitive to long wavelengths. Experiment 2 showed that people with old eyes ($N = 10$) made the adjustments expected in people who see through a yellowish filter.

● **A shift to lower peak temporal frequency with age**

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Psychophysical and visual-evoked-potential (VEP) research has suggested that ageing results in a decline in the processing of temporal information. We investigated temporal processing in the elderly by assessing VEP responses to sinusoidally modulated light of various temporal frequencies. Steady-state VEPs at 20% and 80% contrast were recorded in a young (aged 23.9 ± 5.5 years), and an elderly (aged 72.3 ± 5.5 years) group. Signal-to-noise ratios (SNRs) and phase values at the first and second harmonics were evaluated. At 20% contrast, the young and elderly groups produced peak SNRs at medium temporal frequency (12 Hz). The elderly showed lower SNRs than the young, uniformly across the temporal range. At 80%, the peak response of the elderly shifted to 6 Hz. Response phase as a function of stimulus temporal frequency was used to estimate the delay of the visual response. Results were similar for the young and the elderly, with the exception of the 2nd harmonic responses at 80%, when the estimated delay was significantly longer in the elderly compared to the young. Results suggest that at high contrast the pathway transmitting temporal information at higher frequencies may saturate in the elderly, leaving the slower cells to respond. Alternatively, ageing may result in a decline of the VEP flicker subsystem processing middle temporal frequencies.

● **Randomisation reduces the impact of crowding in older adults**

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Bouma (1970 *Nature* **266** 177–178), showed that young adults identify letters less accurately when they are flanked by number signs, more so with greater eccentricity. In a replication of that study, I found that older adults are more susceptible to crowding than are younger adults (Fine, 2002, Cognitive Aging Conference, 19 April). Here, I compared the impact of flanker-to-target distance on crowding in younger (18–35 years old) and older (60–75 years old) adults. Letters were presented at fixation and ± 1 and ± 2 deg, alone and flanked by the letter x on each side (eg xax). Flanker distance was 0.5, 1.0, and 2.0 deg. When flanker distance was random from trial-to-trial, there were no effects of age ($F_{12,168} < 1.0$ for the age group \times letter location \times flanker distance interaction). For both groups, letters were identified less accurately farther from fixation when the flanks were close to the target. When flanker distance was blocked, age had a significant effect ($F_{12,156} = 10.3$, $p < 0.01$ for the three-way interaction). Flanker-to-target distance had little impact on younger observers, but the 0.5 and 1.0 deg flanker-to-target distance reduced performance significantly for the older group. Further research is required to investigate the apparent change in strategy between the random and blocked conditions.

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● **Effects of aging on the useful field of view: predictability of target location and the distribution of attentional resource**

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Characteristics of the useful field of view were examined for younger and older adults. Sixty-five observers, with ages ranging from 19 to 84 years, participated. Under focused-attention condition, observers performed central and peripheral vision tasks in separate blocks of trials. The central-vision task was discrimination of single target letters. In peripheral-vision task, the target was presented at one of eight possible positions arranged elliptically. In 81% of the trials, the target was presented clockwise at the immediate next sequential position. We defined this kind of targets as ‘regular targets’, and others as ‘irregular targets’. The peripheral-vision task consisted of discriminating between a regular target and an irregular one. Under divided-attention condition, observers performed the central and peripheral tasks simultaneously. The presentation duration was 70 ms. Performance in both central-target letter discrimination and peripheral-target discrimination was measured. As regards reaction time, there were significant effects of age in the peripheral task. Under divided-attention condition, the performance of the peripheral task was further impaired. The effect of age on the reaction time with irregular targets was most noticeable. But, in the central task, no effects of age were found in the focused condition. The relevant factors are discussed in terms of the distribution of attentional resources.

● **The effect of ageing on visuomotor control**

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Alterations in oculomotor function provide a behavioural index of the impact of ageing on the visuomotor system. Smooth pursuit (SP) is particularly dependent on cortical processing, and therefore a promising tool for investigation of the effects of ageing on cortical structures. We measured SP latency in step–ramp and gap–step–ramp tasks in two groups of neurologically and orthoptically normal individuals: an older group aged 60–90 years (mean: 71 ± 5 years) and a younger control group aged 18–23 years (mean: 21 ± 2 years). Infrared oculography was used to record horizontal eye movements made in response to targets which stepped randomly 5 deg left or right and moved at 14 deg s^{-1} back through the centre of the display. In interleaved tasks there was either no gap or there were gaps of 100, 200, or 400 ms. Quantitative analysis demonstrated an increase in SP latency for the older group across all conditions, and a significant correlation between age and SP latency ($p < 0.001$). There was also a directional asymmetry in age/latency relationship (leftward slope $>$ rightward slope; $p < 0.0001$), and an asymmetry in the gap effect on SP latency (reduced for rightward pursuit; $p < 0.001$). These results demonstrate that SP initiation is modified in normal healthy ageing and that there may be a hemispheric asymmetry in this ageing effect.

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- **Velocity constancy in a video environment with normally sighted and low-vision individuals**
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Can stationary observers judge the velocity of vehicles passing on both sides of a road, and presented on a video monitor? Velocity estimations were made of vehicles passing a fixed video camera. Their true velocities were measured with a radar speed gun. The video stimuli were presented in either the original video (RGB) format or were classified into seven high-contrast colours with the aid of a colour classification scheme developed for low-vision patients (Sheehan, 1999, unpublished undergraduate manuscript). Two questions were addressed here: (i) are people able to make judgments of the velocity of moving vehicles when these have different retinal velocities, being at different distances? (ii) Could low-vision patients make similar judgments both in the RGB and the high-contrast labelled conditions? Velocity estimations by low-vision patients, sighted undergraduates, and age-matched controls were obtained. The accuracy of estimations and constancy between near and far stimuli, were investigated. The accuracy of estimations was moderate with a tendency toward overestimation of velocity across all three participant groups. Constancy across viewing distance was largely maintained. Differences between participant groups were observed but all groups could perform the basic task. There were no differences in velocity constancy between the original RGB format and the colour-classified format. This suggests that, although the accuracy of velocity estimation in a video-based experiment may be somewhat low, constancy is maintained. The wider implication for the design of a low-vision mobility system using a colour classification scheme is that velocity estimations can still be made in spite of the reduction of distance cues, and constancy remains. This suggests that a video system based on high-contrast colours may be useful as an aid to low vision.

VISUAL SEARCH

- **How much memory does oculomotor visual search have?**

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Evidence indicates that the eyes are guided during serial visual search by memory for items that have already been inspected and dismissed (eg Klein and MacInnes, 1999 *Psychological Science* **10** 346–352). Some data suggest that functional memory for search history may be of exceptionally large capacity (Peterson et al, 2001 *Psychological Science* **12** 287–292). However, it is possible that these large estimates actually reflect the operation of a limited-capacity buffer buttressed during standard visual search by mnemonic scanning strategies (eg stereotyped scanning, geographic chunking of inspected items). Here, we employed a novel, gaze-contingent visual-search technique to estimate the capacity of true memory for search history, uninflated by mnemonic scanning behaviour. Results indicate a store of roughly 3–4 item capacity, with memory for a given item decaying as a function of the number of fixations since it was last inspected. This memory appears to be both object-based and space-based, but also shows evidence of a coarse space-based component. An experiment comparing performance in younger and older adults yielded more robust memory for search history in the aged. In total, data suggest that oculomotor search is guided by a modest buffer of literal memory for search history, perhaps aided at times by mnemonic scanning strategies.

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- **Pupil size as a measure of task difficulty in vision**

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The extent of dilation of the pupil of the eye has been found to be a reliable indicator of the extent of cognitive load during task performance. While this has been repeatedly shown with auditory input in various domains (including language processing, mental arithmetic, and memory tasks), the existence of the pupillary light reflex has made it difficult to isolate the 'cognitive load' component of the pupillary response when processing visual input. Here, we demonstrate that, with appropriate control measures, pupillary response during performance of a visual-search

task does relate in a lawful manner to task difficulty (manipulated specifically in terms of small or large set size, and homogeneous versus heterogeneous distractors). Furthermore, by comparing pupil size during performance of two different tasks which are similar in reaction times—visual search and counting—we found that the pupillary response distinguishes between task demands during performance in a way that traditional reaction time measures do not. We conclude that the pupil can provide insight into the extent and nature of cognitive processing occurring in response to simple visual stimuli.

- **When form and motion combine difficult search becomes effortless**

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We previously showed that orientation discrimination of a target line segregated by small orientation contrast from a line-texture background oriented at 45° improved with left–right apparent motion as compared to static stimulation. We ask now whether bottom–up attentional mechanisms (as opposed to top–down focal attention) are triggered by moving but not by static targets, either because motion acts as a bottom–up attention cue to select the target (background exclusion) or because moving lines are more salient than static ones. We measured how sensitivity (d') varies with background numerosity. For ortho-targets (ie more orthogonal to motion direction and more vertical than background lines), d' was larger than for static targets of either orientation and independent of background numerosity. For more-horizontally moving targets (iso-targets), d' did not differ from static ones and, as for static targets, decreased with background numerosity. This indicates that detection of both static and iso-targets, but not of ortho-targets, involves focal attention, a result ruling out the background-exclusion explanation. Increased salience of ortho-targets and their detection, automatic and independent of background numerosity, may instead result from motion energy, since it can be mathematically demonstrated that it is higher for ortho-targets, when extracted at the earliest computation stage by a motion sensor responding to orientation and motion direction conjointly.

- **Specificities of learning in combined-feature search: implications for underlying coding mechanisms**

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Eleven subjects were trained with 1200 trials of search for a 180°-rotated letter L amongst 90°-counterclockwise-rotated Ls, then tested with three transfer stimuli in which target, distractors, or both were changed. According to signal detection theory, learning both increases signal enhancement and external noise exclusion by enlarging the distance between target and distractor response distributions (Doshier and Lu, 1998 *Proceedings of the National Academy of the USA* **95** 13988–13993). Similarly, the SERR (search via recursive rejection) model (Humphreys and Muller, 1993 *Cognitive Psychology* **25** 43–110) would assume a learning process based upon boosting of target template and distractor grouping and rejection. Finally, the FRS (Fogel, Rubenstein, and Sagi) model of texture segmentation [Sagi, 1991, in *Channels in the Visual Nervous System: Neurophysiology, Psychophysics and Models* Ed. B Blum (London and Tel Aviv: Freund) pp 397–424] would assume a learning process based on the tuning of the appropriate filters to the orientation of target and/or distractor elements at the spatial frequency corresponding to the size of whole elements. Our results show that learning transfers to a stimulus where low-pass-filtered orientation of the target and distractor is the same (changing either target or distractors); learning does not transfer to a stimulus where both target and distractors are changed; learning abolishes the differences between present and absent responses. Learning may be based upon either additive internal noise reduction and external noise exclusion (Doshier and Lu, 1998), or target template enhancement and distractor grouping and rejection (Humphreys and Muller, 1993).

- **Relationship between localisation and discrimination thresholds in multiple Gabor targets**

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Localisation or discrimination thresholds were measured for spatial-frequency (SF) targets in multiple Gabor distractor arrays. Localisation required the position of the oddball to be located (single-frame and two-frame). Discrimination required observers to say whether the target had a higher or lower SF than the distractors (single-frame) or whether its SF increased or decreased (two-frame). SF on target and distractors was systematically covaried. This allowed us to test two simple predictions: first, that localisation sensitivities depend upon the target–distractor SF difference; second, that discrimination sensitivities are proportional to the SF signal averaged

across target and distractors. These predictions were confirmed for certain combinations of target and distractor SF, and disproved for others. Observers can switch from a global discrimination strategy to a local one when the global signal is low and the local target–distractor difference is high. The baseline localisation/discrimination ratio did not vary significantly with eccentricity, task, or between observers. We conclude that pooling of signals across multiple targets can be efficient without being ‘compulsory’.

[Supported by the Wellcome Trust.]

- **Space-based and object-based functions of visual attention**

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Space-based accounts of visual attention describe the attentional focus as a limited spatial region in which processing is enhanced. According to object-based accounts, attention selects objects, not regions in space. This implies that the number of objects is limited but not the extent of space on which they are distributed. Possibly this controversy cannot be solved universally across tasks. We investigated space-based and object-based limitations in two types of inefficient visual search: low distractor–distractor-similarity and high target–distractor-similarity (Duncan and Humphreys, 1989 *Psychological Review* **96** 433–458). Different numbers of objects were presented tachistoscopically on four concentric regions in space. A central cue manipulated the spatial extent of the attentional focus. When a predefined Landolt C orientation among heterogeneously oriented distractor Cs had to be detected, the sensitivity depended on the set size (even with constant object density), but not on the spatial extent of the focus. When the target was a horizontal ellipse among (highly similar) vertical ellipses, the sensitivity depended on the set size as well as the spatial extent. With two more experiments, low-level visual effects were ruled out. We conclude that attention is purely object-based if a categorically defined target has to be detected. However, if objects have to be compared with each other (in order to detect a target among highly similar distractors), a space-based component is involved.

- **Is inhibition of return a perceptual effect? Contradictory findings using two ‘perceptual’ measures**

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Inhibition of return (IOR) refers to the slowing of reaction times to a target when a preceding stimulus has occupied the same, rather than a different, location in space. There is a general disagreement concerning the mechanisms through which IOR can operate, many authors postulating that IOR results from an attentional biasing against previously inspected locations, whilst others argue that IOR is more indicative of motor influences. Some evidence against an attentional view of IOR is the failure to observe IOR in temporal order judgment (TOJ) tasks, a method traditionally used to measure the location of attentional focus. We report data from experiments in which observers were required to make either detection responses or temporal-order judgments to identical stimulus sequences. Although both these tasks are usually considered to be ‘perceptual’ tasks, IOR was obtained for only one of them (as well as for a standard reaction-time task). We conclude that some ‘perceptual’ tasks may be more perceptual than others.

- **Developmental changes in performing visual-search tasks**

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The development of perceptual, motor, and intellectual abilities and their interrelationships in school-aged boys was investigated. Children (aged 7, 9, 11, and 13 years) performed visual search for conjunctions of orientation and colour or size, applying stimulus onset asymmetry, motor coordination tasks, and general intellectual ability measures. Although the general response time in visual-search tasks declined across age groups, the inspection times per element did not reveal differences between the age groups. The slopes gained by pre-cueing compared with simultaneous presentation of features did not reveal significant differences between the age groups. The results indicate that the specific mechanisms conducting visual search are relatively mature by seven years of age, whereas motor abilities reach a developmental plateau by nine years of age, and general intellectual ability continues a gradual improvement. The intellectual ability predicted response accuracy on visual search for conjunctions of colour and orientation. An asymmetry in processing of visual feature conjunctions emerged, indicating the possibility of perceptual segregation on the basis of colour or size, but not of orientation, in order to facilitate the subsequent search for feature conjunction.

● Repetition priming by distractors is independent of attentional blinks

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The aim was to examine lexical access during and outside the attentional blink (AB). The main experiment interleaved a speeded matching task with a speeded lexical decision task. In the matching task, two identical or different targets (T1 and T3) were embedded in an RSVP (rapid serial visual presentation) stream of non-words. A prime (T2: a word or non-word) was temporally placed between T1 and T3 so that T2 occurred either during or outside the AB of T1. T2 acted as a distractor and no response was required to it. After the matching response, a 4-letter string (identical to or different from T2) was presented for lexical decision. Results showed a significant repetition effect for words (50 ms or so), but not for non-words. However, results in an explicit memory task revealed chance level of recognition for T2. In conclusion, the RSVP words being monitored automatically activated their internal representations within 100 ms, independently of AB. Although the lexical activation of a distractor word is still quite substantial up to more than 3 s after its onset, it has little impact on explicit memory. The results allow us to fine tune the AB models regarding the processing limitation.

● What is the optimal scan path for search with a limited field of view?

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Our aim was to model search performance for a given scan path (speed, zoom, field size). Subjects searched with a limited field of view (1024 pixels \times 768 pixels) through a large panoramic image (16384 \times 1536 pixels, or 75 deg \times 20 deg in reality) of a heath containing a target (a camouflaged person). From trial to trial the target appeared at a different location. Predefined (horizontal) scan paths were used with constant speed. The subjects hit a button as soon as the target was spotted. We determined the effect of scanning speed, zoom factor (1, 2, and 4), size of the field of view, and target location on search performance (detection time and detection probability). Our findings were as follows. (i) The distribution of response times (the time from appearance to detection) was independent of zoom factor and speed. (ii) Response time was largely independent of the vertical target position, although targets near the horizon were smaller and therefore less conspicuous. (iii) The number of hits was lower for targets appearing closer to the horizon and decreased with increasing speed. It thus appears to be advantageous to foveate the locations where targets with the lowest conspicuity are expected: only when the conspicuity is smaller than expected, detection will be worse.

● Do perceptual learning effects transfer between hemispheres?

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We found hemispheric differences in feature search (Pavlovskaya et al, 2001 *Spatial Vision* **14** 151–173) when search arrays were within one hemifield, rather than when target elements were lateral but array central. In parallel, Ahissar and Hochstein (1997 *Nature* **387** 401–406) found that perceptual learning transfer across position (or orientation) depends on task condition: learning effects transfer when the task is easy (large target–distractor difference; limited target-position uncertainty; long test-to-mask stimulus onset asynchrony) and are considerably specific when conditions are harder. These differences were related to cerebral sites of modification due to experience: hard tasks were seen as requiring low-level (specific) representations while easy tasks are performed by high-cortical-level mechanisms alone. We now ask if interhemispheric transfer also depends on task difficulty. Hard-task learning should not transfer owing to the local nature of low-level receptive fields. Easy tasks, on the other hand, might transfer more easily within than across hemispheres. Subjects performed colour and orientation feature search, each within one hemifield. Sessions were divided, one-half easy and one-half hard. After training, we switched the sides of the colour and orientation tasks. We found nearly complete transfer for easy conditions, and considerably less with difficult conditions. Our results support the notion that feature search with easy conditions is performed at high cortical levels where representation mechanisms include much of the visual field on both sides of the vertical meridian.

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● **Stimulus density does not affect saccadic search performance**

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Visual acuity declines with retinal eccentricity. During saccadic search, eccentricity of nonfixated elements decreases with increasing stimulus density. Does increasing stimulus density lead to faster and more efficient search per stimulus element?

Subjects had to search for a circle (target) among Cs with randomised orientations (gap left, right, up, down). Stimulus density was manipulated by changing the number of elements (36, 64, 100, 144) while keeping the stimulus size (40 deg × 30 deg) constant. We also varied target discriminability by changing the size of the gap in the C (0.095 deg, 0.19 deg, 0.3 deg). We adopted two measures to estimate search performance: search speed per element (mean search time divided by the number of elements) and search efficiency per element (the number of elements divided by the number of saccades). In these measures the effect of set size is eliminated and only the effect of stimulus density remains. Increasing target discriminability resulted in a faster and more efficient search per stimulus element. Stimulus density did not influence search speed and search efficiency per stimulus element, nor was there any interaction between stimulus density and target discriminability. This indicates that the effect of reduced retinal eccentricity of nonfixated elements was counterbalanced by lateral masking.

● **Visual search and simultaneous short-term-memory task**

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Our purpose was to determine whether a simultaneous short-term-memory task affects the speed of visual search and eye movements. In a serial search task an uppercase letter was searched for among randomly selected numerals. Presentation of the stimuli was controlled by a staircase algorithm. Threshold search time with the probability of 0.84 of correct answers was determined. Thus, the time used for decisionmaking and motor reaction were excluded. Eye movements during the search were recorded with a video eye-tracker. In the short-term-memory task, a string of randomly selected characters (numbers, letters, or both) was presented before each search trial, and subjects rehearsed it actively during search. After the search trial, one of the items was shown and the subject was required to report the next item in the string. In a control condition, the subjects performed the search task only. Threshold search time and eye movements seem to be unaffected by the simultaneous memory load, although the subjects felt that the tasks were demanding. This suggests that there may be no interaction between the information processing used in visual search and holding similar items in short-term memory.

● **Visual search in subjective surface the inducers of which were not collinear**

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It has been reported that visual search for Kanizsa's subjective square is detected in parallel, so that search times are almost independent of the number of distractors (Davis and Driver, 1994 *Nature* **371** 791–793). This result suggests that a subjective surface would be represented in early vision. However, 'pop-out' in the search task could have been caused by a property of the inducers (such as their collinearity) rather than by the pre-attentive creation of a subjective surface (Gurnsey et al, 1996 *Perception* **25** 861–874).

In our experiment, two different search tasks were given. One was a visual search task for subjective surface the inducers of which were not collinear. The other was an asymmetry search task. Results showed that the subjective surface could be detected in a given time independent from the number of non-subjective surface distractors. This finding implies that a subjective surface can be detected in parallel, suggesting that subjective surfaces may be represented in the early visual mechanism. This is in accordance with Treisman's notion that the target defined by the presence of preattentive basic features tends to be easily detected.

● Visual search with binocular disparity

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Vision can use various cues, such as colour, texture, orientation, etc, to detect a target. Having used visual feature search paradigm, Nakayama and Silverman (1986 *Nature* **320** 264–265) indicated that colour and motion are processed ‘serially’ whereas disparity and colour, or motion, are processed ‘in parallel’. Here, I report the results of conjunction search using spatial frequency, orientation, and binocular disparity. Search field consisted of four Gabor patches in the centre, plus six or twelve Gabor patches equally placed on the circumference of 1.25 deg in radius. The Gabor patches had a spatial frequency and an orientation. The spatial frequency was either 1.5, 3.0, or 6.0 cycles deg⁻¹, and the orientation was vertical, horizontal, right-side 45° up, or right-side 45° down. The search field observed through a haploscope indicated that the patches might have had 4.5 min of arc binocular disparity forward or backward in comparison to the central reference. The search target was a misconjugated patch among other patches defined by conjunction of either spatial-frequency, orientation, or binocular-disparity cues. The subjects responded as soon as possible when they detected the target. The search time for all three conjunction cases increased with the set size.

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● Attending in depth does not affect stimulus processing

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Several studies have suggested that it is possible to direct attention in 3-D space (Nakayama and Silverman, 1986 *Nature* **320** 264–265; Atchley et al, 1997 *Psychonomic Bulletin & Review* **4** 524–529). If attention is directed similarly in depth in 2-D space, it is possible that advance knowledge of a target’s depth plane not only helps to direct spatial attention to a relevant location in 2-D space, but also enhances the sensory quality of the representation of a stimulus. To explore this question, three search experiments were carried out in which observers had to search for a digit target among letter distractors. Probability of the target being located in a particular depth plane was varied. Probability manipulations had no effect on performance when search displays were masked and accuracy was the dependent measure. Nor had they any effect when reaction time (RT) was the dependent measure and vergence eye movements were avoided. Only when vergence eye shifts were possible, RT costs were significant. Results suggest that not only is attention in 3-D space different from attention in 2-D space, but attending to a particular depth plane helps performance less than attending to such stimulus dimensions as colour and size.

● A latency-operating-characteristics (LOC) analysis of cross-dimensional interference

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A method for analysing reaction times (RTs) as a function of response accuracy has been developed by Kumada and Humphreys (2002 *Cognitive Neuropsychology* **19** 49–65). This analysis demonstrates time course of interference of task-irrelevant information on selection of task-relevant information. In the present study, this analysis was applied to a phenomenon called cross-dimensional interference (Theeuwes, 1991 *Perception & Psychophysics* **50** 184–193), to clarify the mechanism. Two singletons defined by visual features (one colour and one shape) were present on a visual search display. Participants searched for a pre-specified singleton while ignoring the other singleton. RT distributions for the target singleton were plotted as a function of response accuracy to provide LOC functions. The shape of functions varied with relative salience of a singleton distractor against a target. When a singleton distractor was salient relative to a target, response errors occurred in the fastest end of the RT distribution. This result suggests that attention is engaged to a salient singleton distractor at first and re-engaged to a target. In some cases, unintentional attentional engagement (or attentional capture) to a singleton distractor caused response errors. Although the mechanism of the cross-dimensional interference is controversial, this study showed evidence supporting that the phenomenon is due to attentional engagement to a salient distractor.

- **Reduced crowding from opposite contrast polarity flanks: not filter preselection or 'pop-out'**
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Target identification can be hindered by the presence of flanking contours, a phenomenon known as crowding. For a target letter 'T' which is flanked by similarly shaped objects, crowding is weaker when the target and flanks are of opposite contrast polarity than when they are of the same polarity (Kooi et al, 1994 *Spatial Vision* 8 255–279). We investigated two potential explanations for this opposite-polarity advantage: (i) the observer voluntarily presets filters that preferentially process features specific to the target, and (ii) the unique features of the target result in odd item 'pop-out' and this reduces crowding strength. To prevent the voluntary pre-setting of filters, we randomised the relative polarities of the target and flanks on each trial. To prevent odd item 'pop-out', we added a false target to the display with the same shape and contrast as the target. Neither of these manipulations had an impact on the opposite-polarity advantage. In addition, the relative polarities of the target and flanks did not influence the response time for identifying the targets in the above stimuli. Our results argue against the pre-setting of filters and 'pop-out' as a basis for the opposite-polarity advantage.

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- **Visual search—influenced by Simon effect or visual hemifield?**

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Previously we found that in a visual-search paradigm subjects responded significantly faster when the target was presented in the left hemifield than in the right, irrespectively of whether subjects efficiently searched for features (FS) or inefficiently searched for conjunctions (CS). Here, we asked whether this difference was due to the stimulus–response compatibility between visual hemifield and responding hand (Simon effect), or to a left visual hemifield advantage. We tested fifteen right-handed participants with FS and CS displays, using a 2AFC design and within-subject counterbalancing of hands for target-present and target-absent trials over runs. Reaction times for both hands were equally fast for target-present and target-absent trials. Moreover, neither FS nor CS revealed a Simon effect. In contrast, both hands responded faster to the presence of a target in the left than in the right hemisphere, with larger differences for CS than for FS. This suggests that, even in efficient feature search, subjects were not able to take advantage from stimulus–response compatibility. Instead, both efficient and inefficient search seemed to depend on a right-hemisphere dominance, normally suggested to account for visual attention, or subjects used similar search strategies in both tasks, investigating the left hemifield first.

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- **Reversal of visual scanning and recognition in children with dyslexia**

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Fifty-eight children aged 7–9 years were tested for recognition of eight different Morse-like signals moving in a horizontal direction. Subjects' task was to pursue and recognise the stimuli. Twenty-nine subjects with dyslexia had some problems in resolving this task: only seven dyslexics solved the task whereas the others failed. A majority of dyslexics showed a superiority in the right–left moving condition, a reversal of the left–right scanning in reading. Control subjects showed an equal score in both directions. To test the obtained 'reversal effect' we carried out a second experiment. One hundred and twenty children aged 7–9 years were tested for visual recognition of four forms presented on a screen for a short time. The forms were images of known fruits of similar shape. All possible permutations of the forms were presented in horizontal or vertical rows. The subjects' task was to recognise objects in a row. Sixty-two subjects were pupils with normal ability and fifty-eight subjects with reading disabilities (dyslexics). Dyslexics again showed the 'reversal effect'—they preferred to scan the row in right–left direction ($p = 0.055$, Student criterion). Other subjects showed the 'standard' left–right trend ($p < 0.0001$). The observed reversal of visual scanning may be a contributing factor in the reading disability of dyslexics.

EYE MOVEMENTS

● **Motion perception under involuntary eye vibration**

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Retinal motion caused by voluntary eye movements is never misinterpreted as object motion, as if the visual system discounted the contribution of voluntary eye movements to retinal motion. Yet, involuntary eye movements caused by mechanical eye vibration are interpreted as object motion unless the vibration has high frequency, in which case only image blur is noticed. In these latter conditions, however, a light flickering above the fusion limit is vividly perceived to undergo oscillatory motion over its static surround.

We determined the conditions of this phenomenon, showing that the perceived frequency of illusory oscillation equals the difference between flicker frequency and the frequency of vibration of the eyes. This outcome is explained as a result of the low-pass temporal-frequency characteristic of vision, which further predicts that the same effect should occur if the flickering light is vibrated and observed with static eyes. This prediction was corroborated empirically. We also determined the minimal amplitude of oscillation required to perceive motion as a function of postural stability and the presence of static references, finding an amplitude threshold of 1 min of arc with postural stability in dim-light conditions which increases to 2 min of arc with postural instability in the dark.

● **Noise in the visual system: high-frequency eye tremor improves responsivity and visual acuity in cortical neurons**

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We demonstrate with electrophysiological recordings that visual cortical-cell responses to moving stimuli with very small amplitudes can be enhanced by adding a small amount of noise to the motion pattern of the stimulus. This situation mimics the micro-movements of the eye during fixation. It shows that these noisy movements could enhance the performance of the cells, and suggests that cortical processing involves stochastic resonance. Employing a biophysically realistic model of the vertebrate retina, we show, in addition, that eye micro-movements can be used to enhance the visual acuity of the cortical representation of its retinal input by means of spatio-temporal integration. This mechanism could partly underlie the hyperacuity properties of the visual system.

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● **Event-related fMRI of saccadic response inhibition**

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Inhibition of ongoing or planned motor behaviour is fundamental to every-day social functioning. Several paradigms have been developed to examine neural and behavioural correlates of response inhibition in laboratory situations. We performed event-related fMRI to examine BOLD (blood-oxygenation-level-dependent) activation during a saccadic GO/NO GO task both in gap (fixation point offset 200 ms prior to target onset) and overlap (continuous presentation of the fixation point) conditions. Gradient-echo echoplanar MR images were acquired by using a clinical 1.5 T MRI system (TR = 1.5 s, twelve 3 mm axial slices). Eye position was recorded in the scanner with an MR-compatible eyetracker (CRS Ltd, Cambridge, UK), enabling performance monitoring and discrimination between inhibition and failure of inhibition in NO GO trials. Preliminary results based on data of three subjects reveal stronger activation of right inferior parietal and of dorso-lateral prefrontal cortex (BA 9) during performance on the GO task compared to the NO GO task. In the NO GO condition, right precuneus in parietal, and left anterior cingulate cortex in frontal lobe revealed stronger activation as compared to the GO task. Despite differences in saccadic reaction times, BOLD responses were similar for the gap and overlap conditions. Further analysis with additional participants will be conducted to determine the time course of activation in selected ROIs (regions of interest).

- **Saccades in the dark: fMRI evidence for separate cortical control of intentional eye movements**
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Using functional magnetic resonance imaging (fMRI), we explored the cortical control of reflexive and intentional saccadic eye movements. Subjects ($n = 7$) performed saccades to visual targets (10 deg, randomised left or right) in a step paradigm, while whole brain, EPI T2*-weighted images were acquired in a block design. We compared BOLD responses in this visually guided task to those found when subjects made saccades to imagined targets in the dark. Saccadic amplitude and frequency were determined by an MR-compatible eye-tracker. Saccade latencies to fixation offset were significantly different in the two tasks (mean = 203 ms and 289 ms for the reflexive and the intentional conditions). Saccades to the imagined target location exhibited slightly larger amplitudes (ca 10%) compared to the saccades to visual targets. The results indicate that widespread cortical activation (including striate, extrastriate, parietal, and prefrontal cortex) was present in both tasks. Right extrastriate cortex was more active during the reflexive task, whereas three areas were more active during the intentional task: one in the right precuneus (BA 7), one in right inferior parietal lobule (BA 40), and one in right frontal operculum (BA 47). These areas appear to be involved in the control of intentional saccades.

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- **Smooth pursuit performance implicates poor magnocellular functioning in developmental dyslexia**

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It has been suggested that a proportion of dyslexics may have a visual magnocellular deficit, although the relationship between this impairment and reading remains unclear. We investigated the magnocellular hypothesis by examining the initiation of smooth ocular pursuit, a behaviour dependent on the visual magnocellular stream. Dyslexic adults were matched to skilled readers for age, sex, and performance IQ on the basis of psychometric tests. The psychometric battery included tests of phonological processing, speed of processing, and verbal ability. In a step-ramp smooth pursuit task, participants tracked a moving target (speed 14 deg s⁻¹) presented on a visual display while horizontal eye movement was recorded by infrared oculography. The effect of both single stationary distractors and temporal gaps was also examined. Pursuit latency (measured quantitatively offline) was significantly increased in dyslexics across all conditions, demonstrating a poorer performance in dyslexics. These results are consistent with a magnocellular deficit in the dyslexic group, although it does not reveal that this deficit explains their reading difficulty. There was also clear evidence of poor phonological skills in this group. The nature of the relationship of both measures to reading performance has been examined.

- **Saccade automaticity and pursuing eye movement**

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On the basis of our previous research on eye movements in normals and in pathology (1967–1997) the concept of saccade automaticity was formulated, according to which the basic part of saccades is generated automatically, without any external and internal stimuli (Filin and Filina, 1989 *Zhurnal Vysshei Nervnoi Deyatel'nosti* **39** 603–608; Filin, 1998, Moscow, TASS-advertisement 317). The purpose of the present work was a study of the effect of smooth-pursuit eye movements on saccade automaticity. Eye movements of adult subjects were recorded by the photoelectronic method (highlight of subject's eye by infrared light and projection of the eye image on photoreceiver) when fixing immovable point and during smooth pursuit of point motion. It was shown that the average intervals when fixing a point and during smooth pursuit of its motion, based on the data received from six subjects, had very close values: 0.50 ± 0.29 s and 0.51 ± 0.27 s, respectively. This points to the identical number of saccades in both cases, in spite of the fact that there were only involuntary saccades in the first case and involuntary and reflex ones in the second case. The numbers of saccades were also identical under smooth increase of pursuit velocity. When the reflex saccades interval is equal to 0.4–0.6 s, involuntary

saccades disappear completely. The reflex saccade, in essence, replaces the involuntary one. Therefore the saccadic centre generates any saccade in native mode, that is in the mode of saccadic automation.

● **Impact of visual distractors on static-smooth-pursuit eye movements**

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We studied the effect of moving distractors on the static smooth pursuit of a small target. The positions of distractor onset and the direction and velocity of distractor motion were systematically varied. The main results are as follows. (i) Smooth pursuit velocity is unchanged if distractor and target have similar vectorial velocity. (ii) Presentation of a moving distractor leads to a systematic change of the vectorial eye velocity into the direction of the vector difference between target and distractor movement. (iii) Interestingly, an exception from this rule occurs with a purely horizontal eye pursuit: in this case, a vertically moving distractor cannot induce any vertical pursuit component. (iv) We also observed an effect specific to the eye-movement trajectory: When a distractor appears on the trajectory (eg before or behind the moving target), its influence is significantly larger than when the distractor appears eg above or below the target. This suggests that visual attention is preferentially focused along the movement trajectory. The findings are only in part compatible with a model assuming vector averaging of the motion vectors in the visual field (Lisberger and Ferrera, 1997 *Journal of Neuroscience* 17 7490–7502). They suggest that smooth pursuit is organised in two subsystems, a horizontal and a vertical one.

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● **Roles of attentive processes in integration of eye-movement signal for visual motion perception**

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Roles of attentive processes were examined in combining retinal and oculomotor information for motion perception. Human subjects viewed a display of two moving targets: one moving in horizontal and the other in near-vertical direction. Subjects reported the perceived direction of vertically moving target. Each of the two targets briefly changed in shape or colour during movement. In 'inattentive' (or 'attentive') condition, subjects were also asked to report the number of times the horizontally moving (or vertically moving) target changed, while ocularily tracking the horizontally moving (or vertically moving) target. In 'divided-attention' condition, subjects were also asked to report the number of times the vertically moving target changed while ocularily tracking the horizontally moving target. In 'inattentive' condition, the perceived direction of motion of the vertical target was close to the direction of its retinal image, not compensating for the horizontal eye movements and thus resulting in a large judgment error; whereas, in 'attentive' condition, the perceived direction was close to the direction of true target motion. In 'divided-attention' condition, the perceived error was larger than in 'attentive' but smaller than in 'inattentive' condition. These results suggest that eye-movement information is not available for unattended moving targets and this constitutes a new constraint in motion perception.

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● **Microsaccades uncover the orientation of covert attention**

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Fixational eye movements are subdivided into tremor, drift, and microsaccades. All three types of miniature eye movements generate small random displacements of the retinal image on viewing a stationary scene. Here we have investigated the modulation of microsaccades by shifts of covert attention in a classical spatial-cuing paradigm. First, we have replicated suppression of microsaccades. A rate minimum was reached about 150 ms after cue onset. Second, we found microsaccadic enhancement with a rate maximum at about 350 ms after cue presentation and a modulation of microsaccade orientation towards the cue direction. This influence of attention on microsaccades accentuates their role for visual information processing. Furthermore, our results suggest that microsaccades can be used to map the orientation of visual attention in psychophysical experiments.

● **Visual search in moving and stationary radial patterns**

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How proficient are we in finding a moving object amongst static distractors when we move ourselves? In this study we compared visual search strategies in self-motion displays to those in matched stationary displays. The subjects' task was to either (i) find a dot with a deviating direction of motion in an expanding pattern of moving dots in a simulated self-motion display, or (ii) find a line with a deviating orientation in a matched static version of the first task, consisting of a pattern of radial line segments. To control for target visibility, the deviation in orientation/motion direction was based on individual thresholds of angles required to identify the deviating element in a 2AFC task at six different eccentricity levels. Viewing period was 1.5 s.

Visual search in the self-motion display exhibited fewer saccades, longer initial fixation times, and shorter saccadic amplitudes after the initial saccade than in the matched stationary display. These results suggest that detection performance alone cannot explain saccadic search behaviour, and that different search strategies may be used in moving compared to stable environments. However, both conditions showed reductions in saccadic latencies after the initial saccade, and systematic changes in the distributions of successive saccades.

● **Visual completion and eye movements in a directed visual search task**

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Visual completion is a common process which takes time (Sekuler and Palmer, 1992 *Journal of Experimental Psychology: General* **121** 95–111). Gaze duration and first-fixation duration are indicators of cognitive processes (Rayner, 1998 *Psychological Bulletin* **124** 372–422). We investigated if eye movement recordings reflect completion processes. Subjects searched a screen containing nine objects in a prescribed order while their eye movements were measured. Targets were isolated circles and circles occluded by a square, distractors were isolated or partly occluded squares and mosaic circles and squares. Fixation duration and gaze duration were longest for occluded circles. Both occluded targets and distractors yielded longer first-fixation and gaze durations than their mosaic counterparts. These results indicate that eye movements can be used to investigate completion phenomena and confirm the automatic nature of the completion process.

● **Quickly tapping targets that are flashed during smooth pursuit reveals perceptual mislocalisations**

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To localise a visible structure one has to consider both the retinal location that is stimulated and the eye orientation. During smooth pursuit, the eye orientation changes continuously, so information about the eye orientation has to be synchronised with retinal information. In perceptual studies, subjects have been shown to misjudge severely the position of flashed targets in the direction of pursuit, which suggests that subjects combine retinal stimulation with eye orientation considerably later in time. Perhaps they combine efferent information about a future eye orientation with delayed retinal stimulation. In contrast to perceptual experiments in which targets are misjudged in the direction of pursuit, Hansen (1979 *Vision Research* **19** 1213–1221) found that subjects could accurately hit targets flashed during a pursuit eye movement with a quick hammer blow. This suggests that there may be a fundamental difference between the information that determines our judgments of the position and the information that is used to hit that position. We therefore tried to replicate this finding. Subjects had to quickly tap targets that were flashed during pursuit with their index finger. We found similar mislocalisations to those in the perceptual experiments: subjects systematically tapped ahead of the position of the flash.

● **Temporal changes in exogenous and endogenous selection of fixation position by the eye**

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Eye movements relocate the small area of high retinal sampling density (the fovea) around the world at a rate of about 3 saccades per second. But what is it that targets saccades as we survey the world? Various models exist, ranging from entirely exogenous (stimulus-driven) to entirely

endogenous (stimulus-independent) saccade-targeting theories. Eye movements were recorded as subjects viewed a variety of images of everyday scenes. We found differences in the locations fixated by the observers between images, as well as differences between observers for the same images. Low-level image statistics were extracted at fixation and used to assess likely candidates for exogenous determination of fixation position. These techniques suggest varying roles for contrast, edge content, chromaticity, and luminance in the targeting of eye movements. Analysis of eye-position data over the course of viewing an image showed striking differences in the clustering of fixations over time. Exogenous factors appear to dominate early in viewing but become less strong in the later part of viewing. This change may reflect an increased role for endogenously targeted saccades after a few seconds. These results support models in which the factors that influence saccade targeting change over time.

● **Perception of eye positions**

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In a two-alternative forced-choice psychophysical test human subjects were tested for their ability to perceive their own viewing direction. A small red flash was presented at different horizontal positions left or right from the subjects' eye position on the screen. Eye positions were recorded with an Eyelink infrared system at 250 Hz temporal resolution. Subjects had to indicate whether the flash on the screen occurred left or right of their own eye position. The task was performed during different viewing conditions—fixation or free viewing—and different background stimulation—a static black screen or moving random dots. The results show that, during the fixation task, subjects perceive their eye position very accurately, with performance reaching the 75% correct level for deviations well below a degree of visual angle. During free viewing on a dark background, the accuracy was much less, and a small bias for left or right choices in some subjects was observed. No consistent bias was observed for leftward or rightward moving backgrounds.

● **Ocular torsion induced during settings of a visual line to perceived horizontal and vertical**

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High-precision video measures of 3-D eye position were recorded while the subject made settings of an LED bar subtending 20 deg to visually perceived horizontal (VPH) or visually perceived vertical (VPV) using the method of adjustment (bar speed 4.5 deg s⁻¹). Settings were made in an otherwise darkened room or in the light. Subjects were required to maintain fixation of the central LED while making settings from start positions either side of horizontal or vertical to VPH and VPV, respectively. Results indicated that even a single visual line can induce substantial amounts of torsional rotation of the eye relative to subject's baseline torsional variation in both dark and light. The gain of these eye movements varied between subjects, but bar settings to VPH consistently induced a greater amount of torsion than settings to VPV. Since it is known that the torsional position of the eye influences the perception of visual orientation, our results imply that the psychophysical method used to study the perception of orientation may itself influence the measure of perceived visual orientation.

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● **The development of eye-movement and fixation patterns in learner drivers**

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Eye-movement and fixation strategies of novice drivers have been shown to differ from those of experienced drivers in terms of a reduced visual-search area, fixation duration, size of gaze change, and use of peripheral vision. This study aims not only to demonstrate these differences under real-world conditions, but also to provide evidence for implicit development of eye-movement strategies that enable learner drivers to acquire rapidly the search 'patterns' used by their experienced counterparts. Learners with no driving experience were taken for four driving lessons in a dual-control car with an experienced instructor and their eye movements recorded with a head-mounted eye-tracker. For a period of not more than 20 min during each lesson the learner was asked to drive around a designated route whilst recordings were made. The results so far demonstrate a rapid and distinct change in the saccade and fixate strategy used by learners as they acquire more road experience. With time, visual search becomes wider and priorities change with respect to fixation areas. Points in the scene that are useful for guiding the vehicle are increasingly targeted.

● **A quantitative measure for the spatial distribution of fixations**

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Many studies have demonstrated qualitatively a relation between the spatial distribution of fixations and scene content and task. For example, parts of pictures that are rich in detail are more likely to be fixated than other parts. In order to characterise the spatial aspect of scan paths, we propose a quantitative measure for the spatial distribution of fixations. We examined how this measure is related to scene content and task. We recorded about 50 000 fixation locations of nine subjects in three experiments. In one experiment, subjects viewed a series of pictures with the instruction to look at them as holiday snapshots. In a second experiment, subjects searched for small targets placed in either complex scenes or against uniform backgrounds. We used Voronoi diagrams to define the area (cell) around fixation points. We found that in each task the normalised cell sizes followed a normalised gamma distribution with one free parameter (skewness). Gamma distributions accurately described the spatial distribution of fixations of all subjects. We found in each subject that skewness was lower for search than for viewing, and higher for search in complex scenes than in simple scenes. We conclude that we have found a promising quantitative measure for the spatial distribution of fixations that seems to be related to scene content and task.

● **Evidence for a link between fixation patterns and display structure in reasoning**

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We investigated how the structure of a visually presented question shapes visual exploration of simple displays in a reasoning task. In two experiments, we displayed configurations of four letters to participants and asked them questions about the spatial relationship of two target letters, eg “Is a above c?” Participants’ manual responses (yes/no) and their eye movements were recorded. The type of the question (above vs below) had a strong influence on where participants directed their first fixation (top or bottom), a behaviour that is more likely to lead to a mapping between question and fixation order. We found that target letters were refixated more often than non-target letters. When participants fixated the second letter (c in the above example) before the first letter (a in the above example) they were more likely to then refixate the second letter than the other way around. This behaviour is consistent with the participants forming a correspondence between the question structure and their fixation order. Participants’ fixation patterns appear to show a surface relationship with the structure of the question. This suggests that in some real sense we reason with our eyes as well as our minds.

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● **Do disturbances in social interaction influence visual scene exploration in psychotic patients?**

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Psychotic patients exploring human faces were reported to show patterns of extensive staring (restricted visual scanpaths and longer fixation duration), irrespective of suffering more from negative or from positive symptoms (Williams et al, 1999 *Schizophrenia Research* **40** 189–199; Manor et al, 1999 *Biological Psychiatry* **46** 963–969). Here, we tested whether these scanpath abnormalities depend on the visual stimulus material used, and thus underlie aspects of disturbance in social interaction. Eye movements (SMI eye tracker) of psychotic patients and age-, gender-, and education-matched control subjects were recorded, while participants viewed images of human faces, landscapes, and fractals. Patients with negative symptoms mostly showed extensive staring. For patients with positive symptoms, exploration strategies varied from extensive staring over normal exploring to extensive scrutinising. Individual exploration strategies did not change with the stimulus material used. Instead, there were significant differences between the patients and the control group in the vertical distribution of subsequent fixations, but not in lateral distributions. Taken together, this suggests that not disturbances in social interaction but rather sensory characteristics influence scanpath abnormalities in psychotic patients.

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LIGHTNESS AND BRIGHTNESS

● Sinusoidal surrounds elicit both simultaneous contrast and assimilation

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Previous studies have shown that brightness induction from complex surrounds can be described as a weighted sum of the brightnesses induced by individual elements of the surround (Zaidi et al 1992 *Vision Research* **32** 1695–1707). We measured perceived brightness of a circular test patch surrounded by a concentric sine-wave grating. The luminance of the test patch corresponded to the average luminance of the grating. The test and comparison patches, presented side-by-side, were identical but in opposite phases (peak/trough) with respect to the surrounding sinusoid. The luminance of the comparison was adjusted by a 2AFC staircase method to match the brightness of the test. Eight spatial frequencies of the surround ($0.5\text{--}5.5\text{ cycles deg}^{-1}$) and five patch diameters ($0.25\text{--}4\text{ deg}$) were used. As a baseline, a classical simultaneous-contrast condition with corresponding spatial parameters was included. At low spatial frequencies, the results conform with earlier studies—simultaneous contrast gets weaker with increasing spatial frequency of the surround. However, at higher spatial frequencies ($1\text{--}2\text{ cycles deg}^{-1}$), contrast unexpectedly turns into assimilation. The critical spatial frequency depends on the patch size, being lower for larger patches. The results suggest spatial-frequency-selective pooling of brightness information rather than straightforward spatial pooling.

[Supported by the Finnish Graduate School in Psychology]

● Individual differences in lightness perception

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Eleven reflectances (range $0.14\text{ to }0.79$) were presented against a white background to inexperienced observers (fifteen extravert, five introvert). Observers were instructed to select a Munsell chip, which they judged to be the same lightness as that presented by the experimenter. Each observer completed four sessions (one session daily) with five runs in each session. ANOVA showed significant differences between observers, in particular significant differences between extraverts and introverts were found. For most reflectances (one exception) extraverts' matches were lighter than introverts'. Significant differences were also found between sessions, but not between trials. Intra-individual differences (within one observer) were nearly as large as inter-individual differences (between observers). The individual inter-quartile ranges averaged for observers and reflectances, made 0.42 Munsell unit. The inter-quartile ranges evaluated for all observers and averaged across reflectances made 0.59 . This, along with the inconsistency of matches made in the different sessions, indicates that each observer in different sessions performed as if he or she was a different observer. All current models of lightness perception offer no explanation of such large intra-individual variability of lightness matching. However, it can be understood if one assumes that lightness judgments are ordinal (rather than interval) in nature (Logvinenko, 2002 *Perception* **31** 201–207).

● Grating induction from real cylinders

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Although grating induction is much weaker than simultaneous lightness contrast from Adelson's tile pattern, we found that the former can be observed from 3-D real cylinders whereas the latter was shown to disappear for a 3-D wall of blocks (Logvinenko et al, 2002 *Perception* **31** 73–82). We presented to our observers 3-D and pictorial displays. The former comprised three cylinders with a horizontal stripe suspended in front of them. The cylinders and stripe were made from the same homogeneous grey card. Illumination was provided by a standard desktop lamp, positioned at 45° to the cylinders and stripe. The curvature of the cylinders and angle of illumination gave each cylinder a perceived lightness gradient. The pictorial display was a photograph of the cylinders with the stripe, taken from the observer's position. Munsell matches were made for sections along the stripe, which were immediately in front of an area perceived as most light and dark on the background cylinders. An averaged Michelson contrast for an illusory grating on the strip was 9.3% and 9.1% for the 3-D and pictorial displays, respectively, with no significant difference ($p = 0.56$). We conclude that grating induction and Adelson's demonstration are different types of lightness illusion.

● **Accurate lightness perception without edges**

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The dependence of lightness perception on the visibility of edges was studied by measuring masking tuning functions for lightness and shape discrimination. Presumably, edges are critical for the discrimination of shape. The stimuli were elliptic patches of uniform luminance (height, 1.8 deg; aspect ratio, 1.04–2). The masks were isotropic 1 octave bandpass noise. The task was to tell whether the patch was lighter or darker than the background and oriented horizontally or vertically. Contrast thresholds for the two 2AFC tasks were simultaneously measured with the method of constant stimuli and as a function of noise centre spatial frequency (0.5–7.5 cycles deg⁻¹). Bandpass masking was observed in both tasks. As the aspect ratio decreased from 2 to 1.04, the peak of the lightness tuning function moved towards lower spatial frequencies (from 2 to 1.5 cycles deg⁻¹) and peak of the shape tuning function moved towards higher frequencies (from 3 to 4 cycles deg⁻¹). Thus, the lightness and shape tuning functions were never completely overlapping. The results are incompatible with edge-based models of lightness perception. Lightness perception is possible without the identification of the shape, and thus without seeing the edges. Moreover, lightness perception seems to be based on lower spatial frequencies than shape perception.

● **Spatiotemporal interactions in lightness and shape perception**

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Detection of the relative lightness and shape of an ellipsoidal grey patch (1.8 deg × 1.0 deg) masked by one octave bands (f : 0.5–7.5 cycles deg⁻¹) of white noise was studied as a function of the stimulus presentation time (37–1500 ms). The task was to tell whether the patch was darker or lighter than the background and whether it was oriented horizontally or vertically.

The contrast threshold versus spatial-frequency functions for lightness and shape were broad-bandpass curves with a maximum in the middle frequencies (1.5–3 cycles deg⁻¹). Above 100 ms the detection of shape required about twice the contrast at maximum compared to lightness, but the difference decreased at shorter presentation times. Below 100 ms both thresholds started rising as seen in numerous experiments. The rise was steeper at low spatial frequencies ($f < 2$ cycles deg⁻¹), and at the shortest presentation time the threshold curves looked more like low-pass than bandpass curves. This is in agreement with the generally assumed role of the magnocellular system in the detection of lightness. However, at long presentation times the low-frequency masks had only a small effect on lightness detection, indicating that given enough time the visual system can make use of the slower parvocellular system for lightness detection.

● **Chromatic discrimination of white under sudden change in condition of lightness adaptation**

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If lightness conditions are suddenly changed from light to dark, eg when driving a car through a tunnel, we can see nothing for a while because the dark-adaptation process takes time. Even during this time, drivers or pilots have to get some important information from visual devices. To investigate the perceptual image at that time, chromatic-discrimination thresholds for white colour were measured by the method of adjustment in an adaptation condition where lightness suddenly changed from daylight to dark. The test stimulus (5 deg, 10 cd m⁻²) was presented in complete darkness after 5 min adaptation in a room that was uniformly illuminated at 50 000 lx. To avoid chromatic adaptation, the test stimulus was presented at 0.5 Hz. The chromatic-discrimination thresholds were obtained as a function of time in the dark following light adaptation. We found that the chromatic-discrimination thresholds were extremely high when the adaptation condition was changed. They were 10–30 times higher than the thresholds under light-adaptation condition. Especially the discrimination threshold for the direction from white to red was high. After 3 min of the illumination change, however, chromatic-discrimination thresholds saturated for all directions.

● **Effects of chromatic contrast on brightness perception**

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We studied the effect of colour on brightness perception by measuring the strength of simultaneous brightness contrast while varying the chromaticities of the centre and surround. The comparison patch presented against a dark surround was matched in perceived brightness to the test patch presented against a bright surround by the method of constant stimuli and a 2AFC task. In the

isochromatic setting, the centre and surround had the same chromaticity (achromatic, red, green, or blue). In the chromatic contrast setting the surround was always red, and the centre either achromatic, green, or blue. The luminances of the dark and bright surrounds and the test patch were adjusted so that their perceived brightnesses matched across chromaticities. Classical simultaneous contrast was observed with achromatic stimuli. When constant chromaticity was added to the stimuli (isochromatic setting), simultaneous contrast was enhanced. However, when chromatic contrast between centre and surround was added, simultaneous contrast was reduced. The reduction was greatest when the centre was blue and smallest when it was green. This dependence of brightness perception on the respective chromaticities of centre and surround suggests complex interactions between colour and luminance processing.

● **The minimum luminance-contrast requirements for stereoscopic lustre**

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Stereoscopic lustre emerges from binocular fusion of a set of black dots in one eye and the same set of black circular rims filled with white in the other eye. The surface appears as a homogeneous graphitic sheen. We studied the effects of the visual angle subtended by the dots (varying between 3 and 0.5 deg), and of the luminance contrast between corresponding dots (varying between 0.75 and 0.97) on the perception of stereoscopic lustre. Stimuli were presented in random order with a mirror stereoscope. The visual angles subtended by the dots varied within each stimulus display while the luminance contrast was varied between displays. Ten observers judged the appearance of lustre. The impression of stereoscopic lustre required a minimum luminance of the light dot of 9 cd m^{-2} when the corresponding black dot had a luminance of 0.7 cd m^{-2} (contrast 0.86). Below that threshold the dots appeared as matt black surfaces without lustre. The dot size had no impact on this threshold. Our results indicate that already very small luminance differences may produce stereoscopic lustre while equiluminous colour stimuli fail to do so (Pieper and Ludwig, 2001 *Perception* **30** Supplement, 103). The missing effect of dot size probably resulted from our use of different sizes within each display.

● **Articulation and lightness constancy**

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Lightness constancy refers to the ability of the visual system to perceive constant surface colour in spite of large changes in environmental illumination. It has been shown that lightness constancy is weaker when the visual field is poorly articulated (Agostini and Galmonte, 1999 *Perception & Psychophysics* **61** 1345–1355). However, among researchers there is little agreement about the meaning of 'articulation'. Beyond the terminological confusion, the scientific issue remains: What factors are relevant to the stability of surface-colour perception? An experiment was run to explore this issue. We systematically manipulated three factors under controlled conditions: (i) number of luminances; (ii) number of surfaces; and (iii) number of reflectances. Lightness constancy improved as the number of luminances was increased, but it seemed to be less affected by the number of surfaces and reflectances present in the scene. In conclusion, our results show that increasing the number of luminances increases lightness constancy. Therefore, since the lightness constancy is directly related to the degree of articulation, articulation seems to be strongly tied to the number of luminances.

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Note: de X, van X, van den X, von X, and similar are all indexed under X

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