heterotaxia. A molecular basis for this might be the discordance of node and LPM asymmetry that was noted in one individual. A low frequency of abnormal expression in the LPM, similar to that seen in *iv* embryos, might also be possible but not yet seen owing to our small sample size.

Determining how *iv* and *inv* normally regulate *nodal*'s nonrandom asymmetric expression awaits the isolation of these genes, and will be of key importance to the study of L–R development. *Nodal*'s role in subsequent asymmetric morphogenesis must also be established. The evolutionary conservation of *nodal*'s L–R asymmetry supports the hypothesis that this molecule is a critical component of the signalling cascade in all vertebrates that culminates in L–R morphological asymmetries. The expression patterns of *nodal* and *Xnr-1* show a remarkable similarity to each other and to *Cnr-1*, suggesting that a basic genetic framework for L–R patterning has been evolutionarily conserved in vertebrates that have quite different mechanisms of gastrulation. □

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Perceived visual speed constrained by image segmentation

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LITTLE is known about how or where the visual system parses the visual scene into objects or surfaces. However, it is generally assumed that the segmentation and grouping of pieces of the image into discrete entities is due to 'later' processing stages, after the 'early' processing of the visual image by local mechanisms selective for attributes such as colour, orientation, depth, and motion[1]. Speed perception is also thought to be mediated by early mechanisms tuned for speed[2–5]. Here we show that manipulating the way in which an image is parsed changes the way in which local speed information is processed. Manipulations that cause multiple stimuli to appear as parts of a single patch degrade speed discrimination, whereas manipulations that perceptually divide a single large stimulus into parts improve discrimination. These results indicate that processes as early as speed perception may be constrained by the parsing of the visual image into discrete entities.

We previously measured the human ability to combine speed information from multiple moving stimuli and showed that whereas increasing the number of stimuli improved speed discrimination, increasing the area of a single stimulus by the same factor did not[6] (Fig. 1). These data do not show the classic summation with increasing area that has been reported for grating detection at threshold contrast[7], and for the detection and direction discrimination of the motion of random dots at suprathreshold contrast[8–10]. Thus, the data shown in Fig. 1 appear to be at odds with the view that speed discrimination is determined early, by local speed-tuned mechanisms[2–5]. Such a framework predicts an improvement in discrimination with increasing stimulus size, either due to an increase in the stimulated area within a unit, or in the number of stimulated units.

To explain this surprising lack of summation, we propose that local speed estimates are influenced by the parsing of the image into discrete entities before or concurrently with the combination of speed information across space. Parsing effectively results in a single independent speed estimate per entity. If the speed estimates from each patch are independent samples from a noisy distribution, then in the multiple-patch condition, averaging across patches improves the estimate of speed. However, in the large-patch condition, there is only a single sample whose precision does not change with the size of the patch, and consequently there is no improvement in speed discrimination.

To test this hypothesis, we measured speed-discrimination thresholds using two complementary approaches. In the fusion experiment, we merged multiple gratings until they became a single stimulus, whereas in the fission experiment, we divided a single large grating into multiple stimuli. Our hypothesis predicts that thresholds will increase as multiple gratings merge to one, regardless of how this is achieved. This is contrary to the prediction of early vision models that assume that the visual field is tiled with arrays of specialized detectors that act in parallel and are insensitive to how the image is parsed.

In the fusion experiment, we merged multiple patches in stages as depicted in Fig. 2. In the multiple-patch condition, three grating patches were maximally separated, and had random spatial phase. In the in-phase condition, the three patches were closer and their phase relationship was consistent with three windows on a full-field grating. In the banana condition, the three patches were fused to form a single banana-shaped patch. In the large-patch condition, the stimulus was a single patch three times the area of the patch used in the multiple-patch condition. Speed-discrimination thresholds for the six observers are plotted, normalized to the threshold in the multiple-patch condition. Five of six observers show thresholds that increase as the multiple gratings are fused into a single patch. Thresholds increase when the stimuli are closer and have consistent phase, increase further when they are fused into the banana configuration, and increase further still going from the banana configuration to the large patch.

In the fission experiment, we divided a single large patch and separated the parts as depicted in Fig. 3. In the occluded condition, we superimposed on the large patch a cross that was darker than the background, thus giving the appearance of a single patch occluded by a cross. In the divided condition, we superimposed the same cross but with a luminance equal to the background, thus perceptually dividing the patch into four quadrants. In the multiple-patch condition, four gratings were maximally separated. Speed-discrimination thresholds for the six observers are plotted, normalized to the threshold in the multiple-patch condition. Starting with the large-patch condition, thresholds are unchanged by the occluder for four of our six observers. This result is consistent with the view that the stimulus in the occluded condition is amodally completed[11] and therefore perceived as a single patch moving behind a cross. However, thresholds do decrease in

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FIG. 1 a, A single frame of the condition with 6 grating patches. b, A single frame of the condition in which a single patch was 6× the size of the patch in a. c Speed-discrimination thresholds versus total stimulus area. Thresholds decreased with increasing grating number (solid symbols), but were unchanged with increased grating area (open symbols). A trial consisted of two intervals, each with the same number of patches. One of the intervals, picked randomly, had all its gratings moving at the reference speed (5.3 ± 0.7 deg s^{-1}) and the other had all its gratings moving at a faster speed (picked from 3 up-1 down staircase). Observers were asked to choose the interval with the faster patches. All gratings had a spatial frequency of 1.5 c deg^{-1}. The number of gratings, n, was kept fixed within a block of trials and was set to be 1, 2, 4 or 6, across blocks. The regular patches in a were windowed by a gaussian with a space constant (σ) of 0.4°. Patches whose area was n times larger had a σ that was a factor of $\sqrt{n}$ larger. The gratings were presented at a fixed eccentricity of 4°, and their angular separation in this experiment was 360°/n. The grating contrast was 20% and the duration of each interval was brief (195 ms) to minimize eye movements. For each experimental condition, thresholds were obtained from a psychometric function of proportion correct versus speed difference between the two intervals. The raw data were fitted with a Weibull function and thresholds estimated as the speed difference that gave 82% correct performance. The thresholds in c are the average of 4 observers' thresholds for that condition, normalized to the threshold for a single regular grating[6].
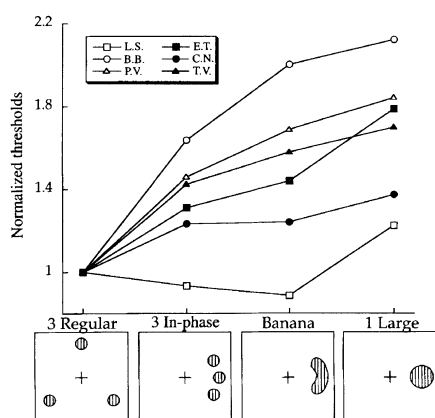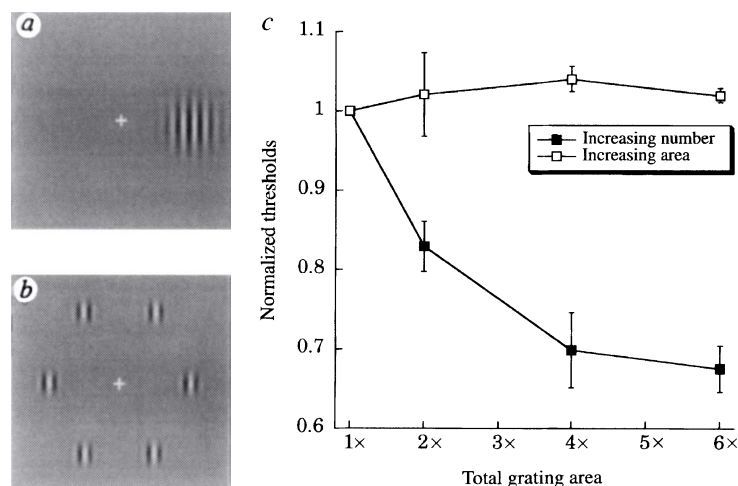

FIG. 2 Fusion experiment. Thresholds for six observers, normalized to that in the multiple-patch condition, are plotted versus spacing condition. The standard deviation for each observer is: L.S. (0.13), B.B. (0.15), P.V. (0.12), E.T. (0.26), C.N. (0.12) and T.V. (0.11). The latter 3 observers (represented by filled symbols here and in Fig. 3) were naive as to the purpose of the experiment. For 5 of 6 observers, thresholds increased as the multiple patches were fused into a single patch. The four conditions were: three regular grating patches maximally separated (the angular separation of their centres was 120°), three grating patches separated by 30° and with a phase relationship consistent with gaussian windows on a full-field grating, three patches fused into a single banana-shaped patch, and a single large circular grating with 3× the area of a regular patch. The spatial spread (σ) of the gaussian window for the regular patches in the first two conditions was 0.4°, and for the large patch in the last condition was 0.7°. The banana stimulus represented a fusion of three regular patches and therefore had the same width and gaussian profile; its (arc) length was ~ 6°. The stimuli in the first three conditions had the same total bounding contour length. Each randomly appeared in one of four configurations on a given trial—that shown, and others rotated by 90, 180 or 270°. Paired one-tailed t-tests across observers on the increase in threshold from one condition to the next were significant as follows: 3 regular to 3 in-phase ($P < 0.001$), 3 in-phase to banana ($P < 0.035$), and banana to large patch ($P < 0.005$). One-tailed tests are appropriate given our a priori hypothesis of a threshold increase.
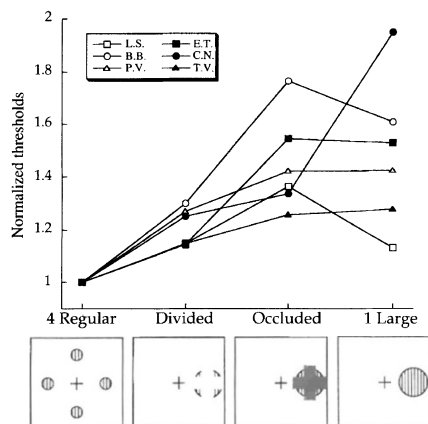

FIG. 3 Fission experiment. Thresholds for six observers, normalized to that in the multiple-patch condition, are plotted versus spacing condition. On average, the standard deviation of the threshold estimate for each observer is: L.S. (0.12), B.B. (0.13), P.V. (0.11), E. T. (0.13), C.N. (0.15) and T.V. (0.07). The four conditions were: a single large patch, the same patch with a superimposed dark cross, the same patch with a superimposed cross equiluminant with the background, and four patches, maximally separated. The last three conditions had the same area and peak contrast. The crosses had a nominal width of 1.3°. They had a centre portion 0.9° wide of constant contrast (10 and 0% in the occluded and divided conditions, respectively), with gaussian edges (σ = 0.2°) tapering to mean luminance. Paired one-tailed t-tests across observers on the increase in threshold from one condition to the next were significant as follows: 4 regular to divided ($P < 0.005$), divided to occluded ($P < 0.008$). The thresholds for the occluded and single large patch conditions were not significantly different ($P = 0.38$).

the divided-patch case, although the only change from the occluded condition is the contrast of the superimposed cross. This is consistent with the divided-patch stimulus being perceived as four discrete parts that are not amodally completed, as in Bregman's compelling demonstration with the broken Bs (ref. 12). Thresholds decrease further in the multiple-patch case when the patches are maximally separated, indicating that proximity is also a factor.

These results show that image parsing affects the integration of local speed signals across space. The most dramatic demonstration of this effect is the significant increase in thresholds (19.7%) from the divided to the occluded condition, despite identical moving regions in both stimuli. A control experiment examined whether this increase was due to an increase in cross contrast per se. Simply increasing cross contrast from 10 to 30% caused no significant change in thresholds ($P = 0.41$, $n = 4$). For the four observers tested in both experiments, going from the divided to the occluded condition caused an average threshold increase 3.9 times larger than that seen in the increased-contrast control. The increase in thresholds from the divided to the occluded condition, and from the in-phase to the banana condition, in conjunction with our earlier results[6], suggests that speed is estimated by pooling speed samples and that effectively only one independent sample is available from each image region that has been parsed as a distinct entity.

It has been shown that the detection of the trajectory of a moving dot embedded in noise can be disrupted if the trajectory is periodically broken by brownian motion, and is not restored by segregating the intervening brownian motion by colour or depth[13]. Although trajectory detection is sufficiently different from speed discrimination to make a direct comparison difficult, one interpretation of this result that is consistent with ours is that the brownian motion in the occluder does not affect local motion estimates in the non-occluded regions, but rather interferes with factors that would otherwise link parts of the motion trajectory together.

Several factors that potentially explain our results can be ruled out. Bounding contour length has little effect as thresholds remain largely unaffected by increasing the circumference of a patch (Fig. 1c) or by superimposing an occluder (Fig. 2) Furthermore, we have shown previously[6] that eye movements, uncertainty about stimulus location, and variation in perceived speed with eccentricity[14], are unlikely to cause the high thresholds in the case of a single patch. However, proximity and phase do appear to influence speed discrimination: bringing the patches closer and making their phase relationships consistent with a single grating cause thresholds to increase (Fig. 2). The grouping of different parts of the image into a single entity appears to make multiple local speed estimates inaccessible, in much the same way that observers are unable to access component speed when viewing coherently moving plaids[15,16]. How might this occur? If the responses of speed-tuned units to multiple patches become increasingly correlated as the patches are brought closer or fused, the benefit of pooling speed information from multiple patches would be reduced[17,18]. Alternatively, inhibitory pooling from surrounding units, either by subtractive[19–21] or divisive[22,23] mechanisms, could decrease the response to extended stimuli, lowering the signal-to-noise ratio and thus increasing thresholds.

The fact that the thresholds in our experiment remain unchanged in the presence of partial occlusion is consistent with the results of He and Nakayama[24,25], who advocate an early parsing of the image into surfaces. Our results extend this view by showing that the parsing of multiple patches, even on a single surface, affects speed perception. Furthermore, there is mounting physiological evidence that neurons in early visual processing areas such as V1 (ref. 26) and MT (ref. 27) are sensitive to image segmentation cues located outside their classical receptive field. Our data provide complementary psychophysical evidence that has important implications for the interaction between local neural mechanisms that code speed. The effect of both proximity and segmentation on speed discrimination suggest that local speed

mechanisms do not act in isolation, but rather in assemblies that have both neighbouring and long-range interactions. □

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Bidirectional modification of CA1 synapses in the adult hippocampus *in vivo*

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MEMORIES are believed to be stored by synaptic modifications. One type of activity-dependent synaptic modification, long-term potentiation (LTP), has received considerable attention as a possible memory mechanism, particularly in hippocampus[1]. However, use-dependent decreases in synaptic strength can store information as well. A form of homosynaptic long-term depression (LTD) has been described and widely studied in the CA1 region of the developing hippocampus in vitro[2–4]. However, the relevance of this model of LTD to memory has been questioned because of failures to replicate it in the adult brain in vitro[5] and, more recently, in vivo[6]. Here we re-examine this important issue and find that homosynaptic LTD can in fact be elicited in the adult hippocampus in vivo, that it has all the properties described in immature CA1 in vitro, and that LTD and LTP are reversible modifications of the same Schaffer collateral synapses. Thus homosynaptic LTD is not peculiar to brain slices, nor is it only of developmental significance. Rather, our data suggest that the mechanisms of LTP and LTD may be equal partners in the mnemonic operations of hippocampal neural networks.

We emulated in vivo the precise stimulation and recording configuration that has been used successfully to elicit homosynaptic LTD in vitro (Fig. 1a). Low-frequency stimulation (LFS; 900 pulses at 1–3 Hz) of the ipsilateral Schaffer collaterals resulted in