Cognitive Neuroscience
9/16/21

Spatial Cognition

1. Parietal cortex: crossmodal and sensorimotor communication hub

2. Impact of parietal injury in humans: sensorimotor control and spatial cognition

3. Area LIP: transition from retina-centered to body-centered visual representation

4. Area VIP: body-centered visual and somatosensory representation

5. Area MIP: retina-centered representation of arm movements

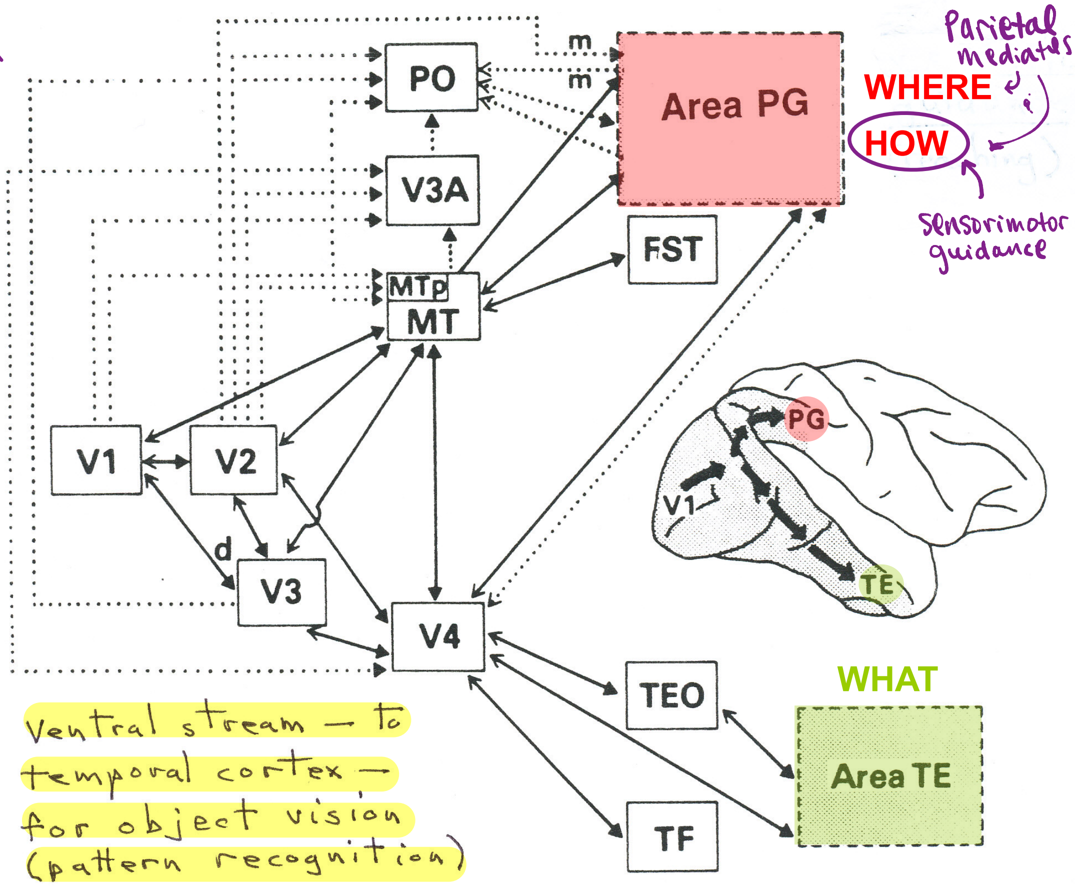
6. Area AIP: matching of grasp posture to object shape

7. Area 7a: spatial cognition

landmark distinction → Desimone & Ungerleider Handbook of Neuropsychology Vol. 2, Ch. 14, 1989.

(flaw → diffuse damage)
Patient w/ damage to temporal lobe
→ ✓ put hand through slot
X orientation of slot
spatial cognition

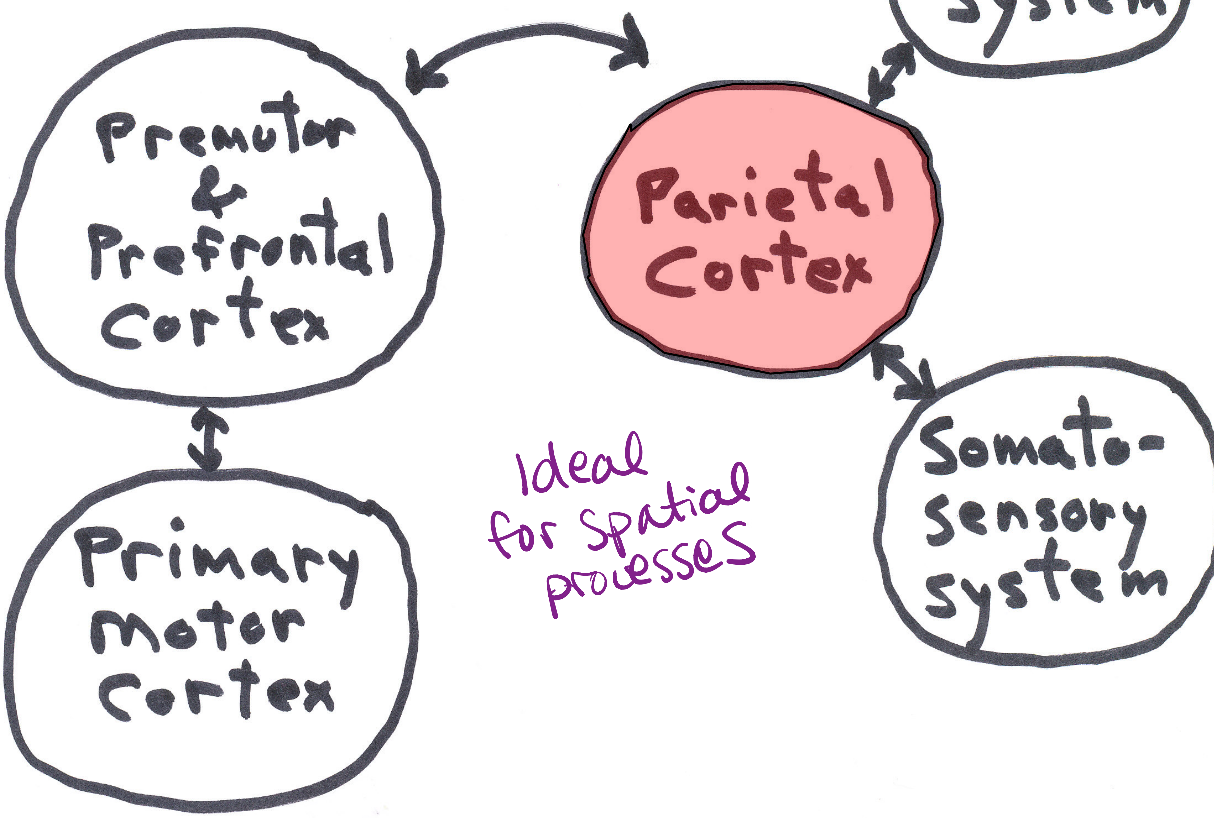
Dorsal stream – to parietal cortex – for spatial vision (landmark task)



Ventral stream – to temporal cortex – for object vision (pattern recognition)

Fig. 3. Schematic diagram of the cortical visual areas in the macaque and their interconnections. Solid lines indicate projections involving all portions of the visual field representation in an area, whereas dotted lines indicate projections limited to the representation of the peripheral visual field. The connections between area V4 and PG are shown in both solid and dotted lines to indicate that the projection is heavier from the peripheral visual field. Heavy arrowheads indicate 'forward' projections, which terminate predominantly in layer 4, light arrowheads indicate 'backward' projections, which tend to avoid granular layer 4 and terminate instead in the supragranular and infragranular layers, and lines with two reciprocal arrowheads indicate intermediate projections (Tigges et al., 1973, 1974; Rockland and Pandya, 1979; Van Essen and Maunsell 1983; Ungerleider, 1985; Ungerleider and Desimone, 1986). 'd' indicates that the projection from V1 and V3 is limited to the dorsal portion of V3. 'm' indicates that the connections of VIP with both V2 and PO are limited to VIP's medial portion. Adapted from Ungerleider and Desimone (1986).

1. Zone where two sensory modalities input
2. Connections to sensory & motor centers

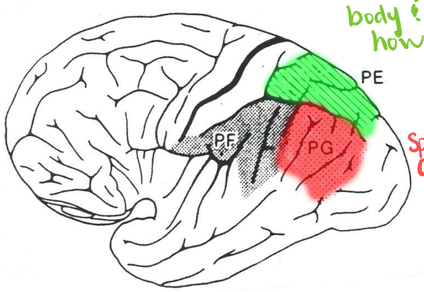


Parietal cortex is both a zone of convergence between multimodal sensory systems and a link between sensory and motor cortex.

Parietal-lobe injury in humans can give rise to a wide range of impairments involving vision, touch, spatial awareness and motor control.

Representation & control of body

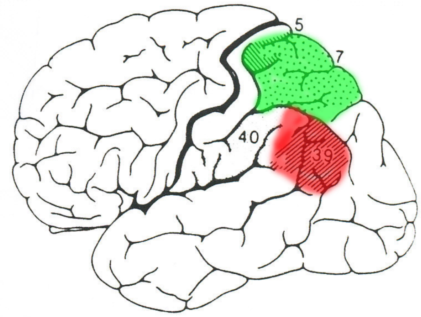
Visual & spatial cognition



body & how fxns

Spatial cognition

von Economo areas



Brodmann areas

TABLE 12.2. Summary of major symptoms of parietal lobe damage

	Symptom	Most probable lesion site	Basic reference
	Disorders of tactile function	Areas 1, 2, 3	Semmes et al., 1960 Corkin et al., 1970
unable to judge shape of things from touch	Tactile agnosia	Area PE	Hécaen and Albert, 1978 Brown, 1972
	Apraxia	Areas PF, PG, left	Heilman and Rothi, 1993 Geschwind, 1975 Kimura, 1980
inability to understand parts of something	Constructional apraxia	Area PG	Benton, 1990
	Acalculia	Areas PG, STS	Levin et al., 1993
	Impaired cross-modal matching	Areas PG, STS	Butters and Brody, 1968
attention	Contralateral neglect	Area PG right	Heilman et al., 1993
Can't appreciate contralateral limb belongs to you	Disorders of body image	Area PE?	Benton and Sivan, 1993
	Right-left confusion	Areas PF, PG	Semmes et al., 1960
	Disorders of spatial ability	Areas PE, PG?	Newcombe and Radcliff, 1990
Can't draw things	Disorders of drawing	Area PG	Warrington et al., 1966 Kimura and Faust, 1987
	Defects in eye movement	Areas PE, PF	Tyler, 1968
Not reaching accurately for things under visual control	Misreaching = optic ataxia	Areas 5, 7	Damasio and Benton, 1979

from Kolb & Whishaw
Human Neuropsychology
4th edition

OPTIC ATAXIA

During the following months, she complained of difficulty in grasping objects on her left. Similarly, when she was preparing meals she could easily take the handle of the frying pan if it was turned to the right but she often did not if it pointed to the left although, she said, she saw it perfectly. These difficulties were linked to the presence of a visuomotor ataxia localized in the left visual field. This was characterized by marked difficulty in grasping objects presented in the left visual field. The patient, moreover, looked for the object at a distance from its real position, usually in front; she explored space like a blind person. If she knocked against the arm of the examiner or the object, correction was immediate and she grasped the object. The disorder was present whatever the object presented, its nature, form, colour and at whatever distance it was placed from the subject. It affected only the left visual field; while grasping objects was perfect when presented in the right lateral field, the gesture was hesitant, unco-ordinated and clumsy and the subject could not grasp the object when presented in the left lateral field. This anomaly existed in the temporal field of the left eye and the nasal field of the right eye.

This difficulty in grasping objects was only observed in lateral vision, that is, when the patient looked in front of her and an object was presented in the left field. Indeed, it disappeared completely if the object was fixed, the gesture then being precise and rapid even if the goal to be attained was situated on the left. Furthermore, previous fixation of the object improved the precision of the movement. If the patient was asked to fix the object presented on the left, then to take it, either after having closed her eyes or after returning to lateral vision, she executed more easily the order given. Performance was even better if one first asked that the object be fixed and then the latter was moved causing an ocular pursuit movement. Thus, fixation of the object overcomes the disorder and previous fixation improves it even if the patient is no longer fixing the object when performing the movement.

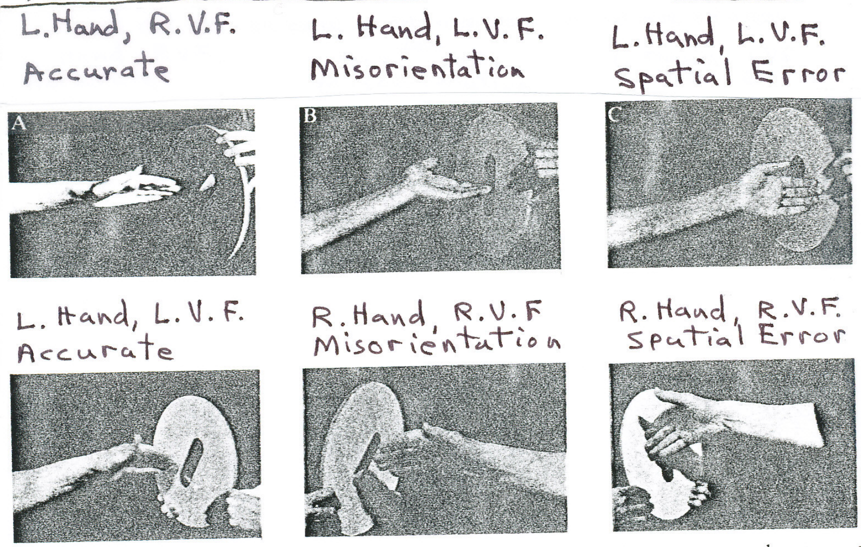
The disorder in left lateral vision was identical whether the right or left hand was used. When the object was presented in the right lateral field the movement was as precise for the right hand as for the left. In this way, if instead of presenting an object, the subject was asked to grasp her own hand, passively placed in her left hemi-field at variable distances, the movement was always precise and adept. It was also precise if she was asked to touch with her left or right hand different parts of her body on the right or left.

· Right superior parietal lobe

· Couldn't reach for things under visual guidance (lateral vision)

Rondot et al.
Brain 100: 355-376 (1977)

OPTIC ATAXIA (MISREACHING) FOLLOWING PARIETAL LESIONS IS NOT JUST A MOTOR BUT RATHER A VISUOMOTOR PROBLEM



Case 2: Right Parietal Lesion

Case 8: Left Parietal Lesion

FIG. 5. The three different kinds of responses observed in the hand orientation test. A, normal response; B, orientation error; C, spatial error. *Upper part*: left hand of *Case 2* in the right hemifield (A) and in the left hemifield (B, C). *Lower part*: left hand of *Case 8* in the left hemifield (A) and right hand in the right hemifield (B, C).

not visual or motor problem alone...

problem w/ transferring visual input to motor output

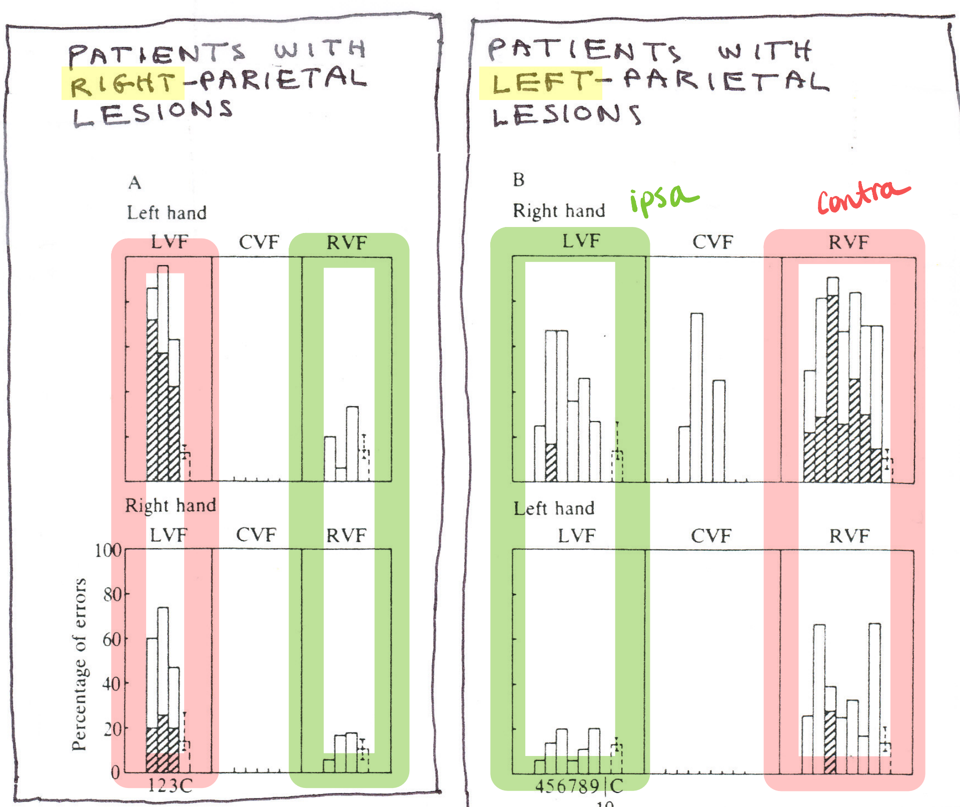


FIG. 4. Distribution of the spatial errors across the different hand-field combinations for each right-damaged (A) and each left-damaged (B) patient, and for the control group (C) during reaching at a visual object. The number of errors is given as the percentage of the total number of trials for each combination and each subject. White bars = corrected errors; hatched bars = noncorrected errors. LVF = left visual field; CVF = central visual field; RVF = right visual field. Note that in both groups of patients there is a 'visual field effect' (i.e., errors with both hands in the field contralateral to the lesion). In the left-damaged group (Case 10 excepted) there is an additional 'hand effect' (i.e., errors with the right hand not only in the right hemifield but also in the left hemifield and in 3 patients also in the central field).

Perenin & Vighetto Brain 111: 643-674 (1988)

Inaccurate preshaping of hand to object in optic ataxia

grasping

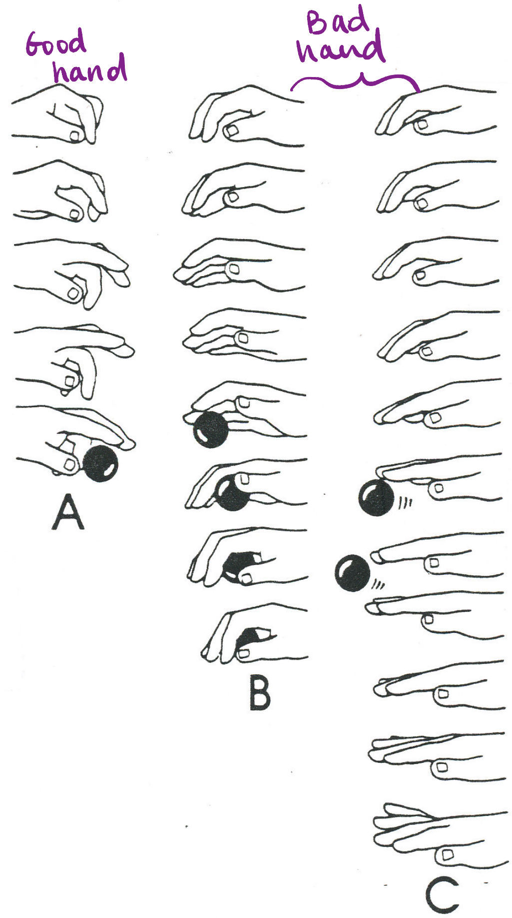
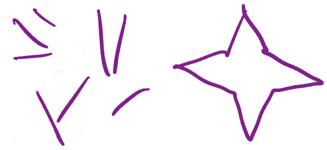


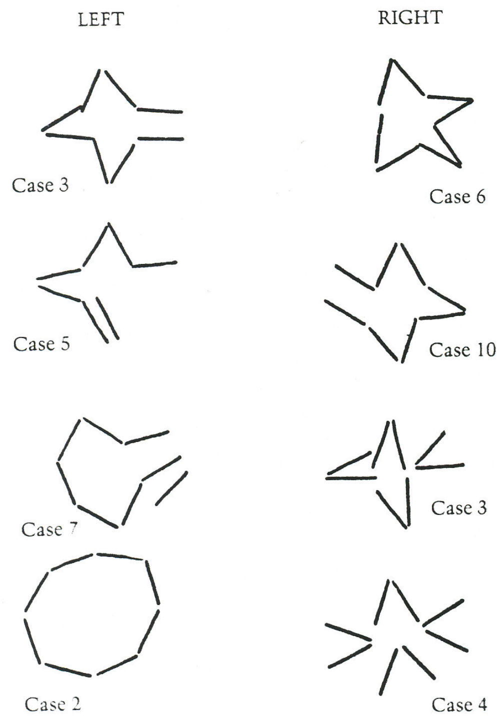
Fig. 15. Pattern of finger grip during reaching in Patient 6 (R.S.). A: normal hand, no visual feedback condition. B, C: affected hand in the visual feedback and no visual feedback conditions, respectively. Redrawn from film

Jeannerod
Behav. Brain Res.
19: 99-116 (1986)

CONSTRUCTIONAL APRAXIA

Contralesional hemispatial neglect





Constructional apraxia – a common result of parietal lobe injury – almost certainly involves a disorder of spatial vision – not just of visuomotor guidance.

Figure 5.6 Copying a star with matchsticks. Examples from and left- and right-hemisphere lesions (McFie & Zangwill, 1960).

extreme difficulty understanding parts

Patients are unable to arrange matchsticks (top) so as to reproduce a model in the form of a four-pointed star. They are unable to arrange tiles (bottom) to match the arbitrary pattern of a visible model.

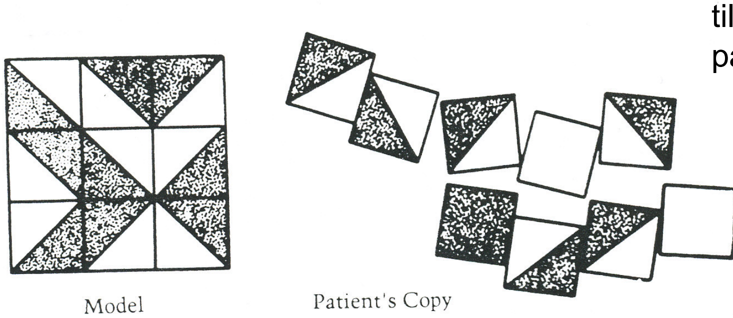


Figure 5.7 Example of constructional failure on Koh's Blocks. (From Critchley, 1953.)

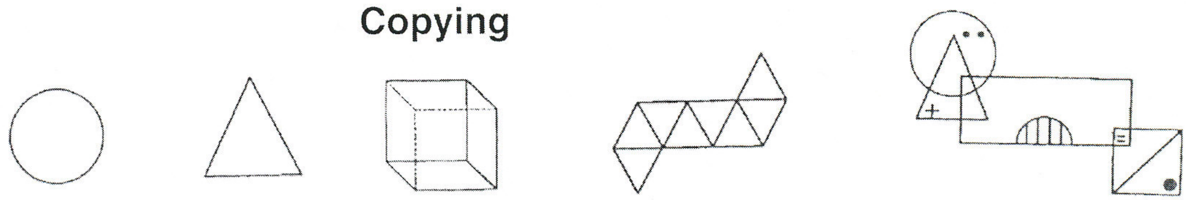
Cognitive Neuropsychology: An Introduction
R. A. McCarthy & E. K. Warrington (1990).

Case description of a patient with impaired visuospatial cognition

Copying and drawing were poor and lacked perspective. Printing in uppercase letters was very disorganized when he wrote looking at the page , but when blindfolded or when writing cursive he was not impaired. The difficulties of reading and writing in print were entirely derived from his inability to locate letters and numbers on the page under visual control. Writing cursive with lowercase letters was good, since this does not require specifically visual positioning of each letter.

Copying

Model

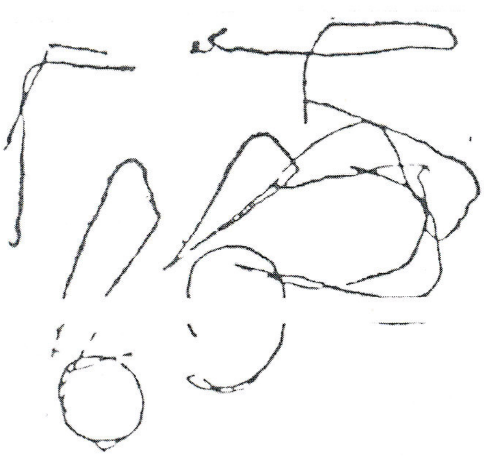


problems w/ volume

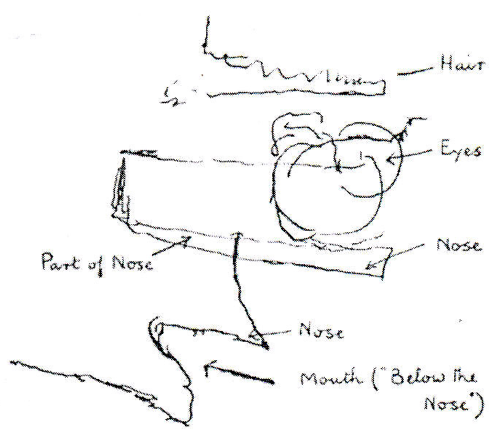
Patient's copy

Free drawing

Bicycle



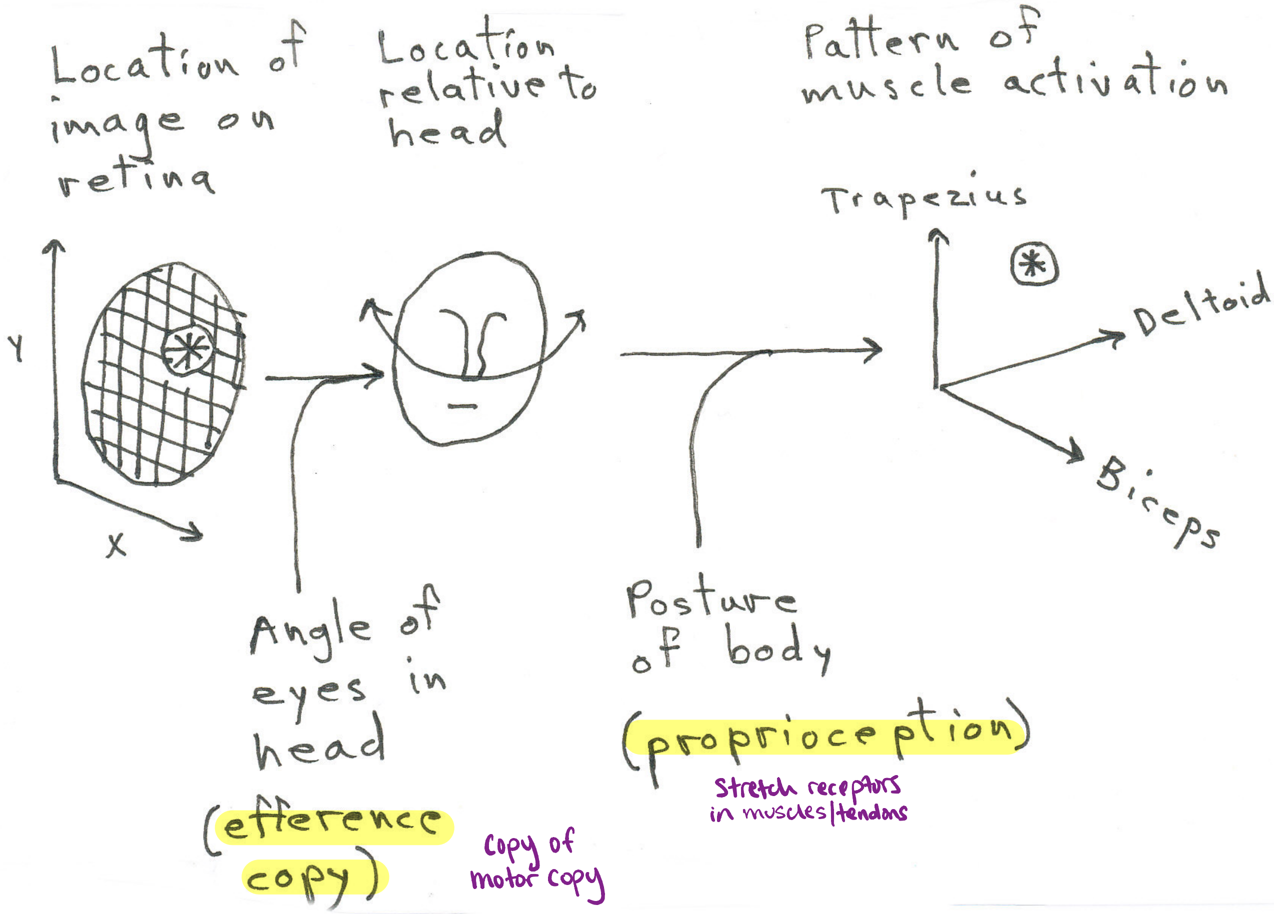
Face



Don't form coherent picture but arranged okay

Why parietal cortex?

Reaching for your coffee cup while reading the newspaper requires using visual information, proprioceptive information and copies of motor signals to compute the cup's location in the workspace around the body.

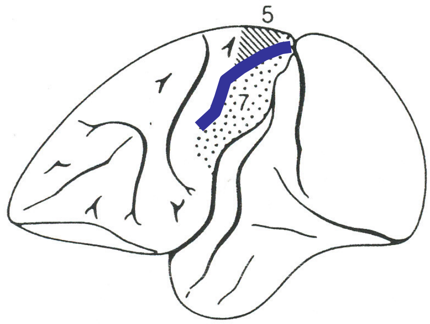


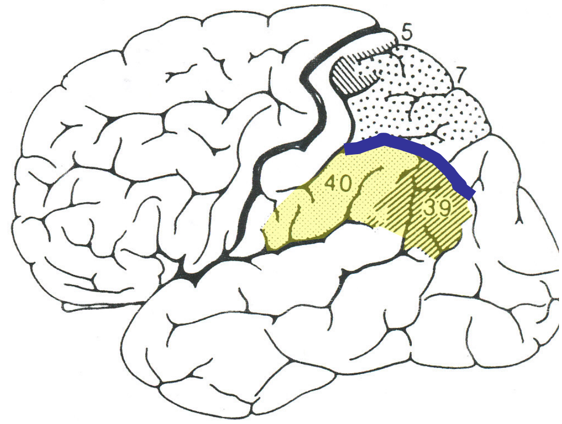
Why the mingling of motor guidance (HOW) with spatial cognitive (WHERE) functions?

Over the course of evolution, mechanisms for representing where things are relative to the BODY (in the service of motor guidance) may have ramified into mechanisms for representing where things are relative to EACH OTHER (in the service of spatial cognition).

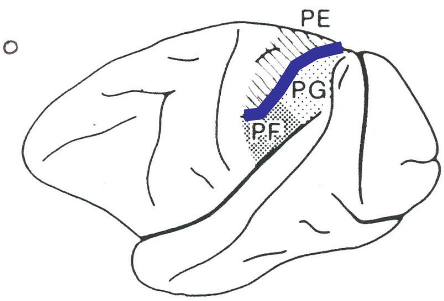
MONKEY HUMAN

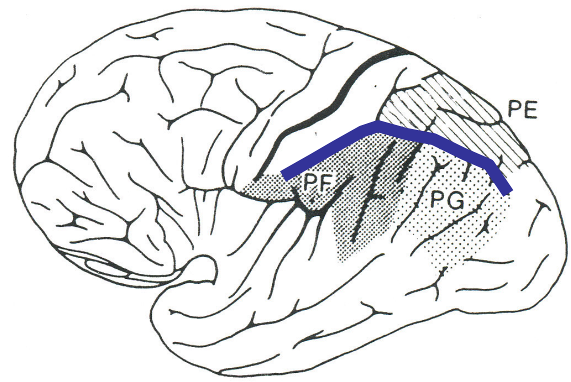
Brodmann areas (poor match)





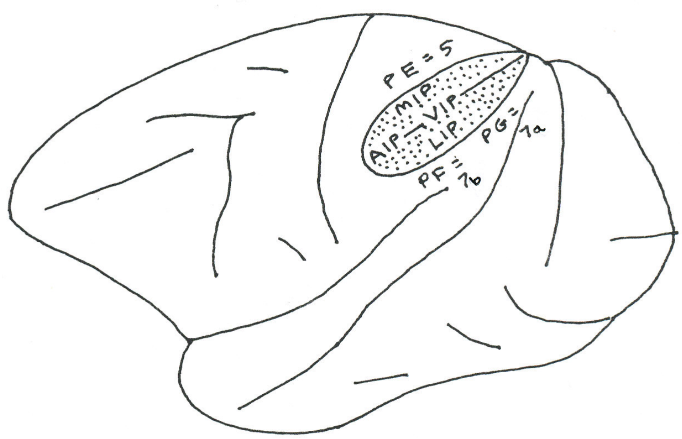
von Economo areas (better match)





AREAS WITHIN INTRAPARIETAL SULCUS OF MONKEY

"IP" Areas defined by single-unit recording



From single-neuron recording studies in the monkey, we know that parietal cortex consists of distinct areas specialized with respect to sensory and motor modality and with respect to the reference frame relative to which location is represented.

Area	LIP	VIP	MIP	AIP
Sensory Modality	Vis	Vis, Som		Vis
Motor Modality	Saccade		Reach	Grasp
Reference Frame	Retina	Head	Retina	Hand/Object

LIP

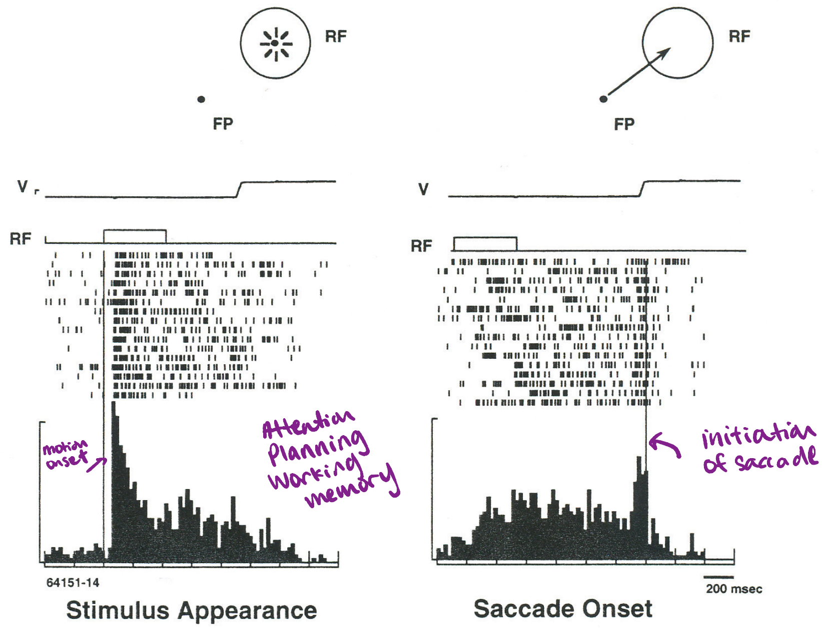


Fig. 2. Response of an LIP neuron in a remembered saccade task. The cartoon above each diagram shows the relative locations of the fixation point (FP) and the receptive field (RF). The time lines show vertical eye position (V) and the onset and offset of a stimulus in the RF. Each tick mark in the raster diagram signifies a single action potential. Successive trials are shown on successive lines, synchronized (vertical line) on the event indicated below the histogram. The calibration bar at left signifies a response rate of 100 spikes/s. In this task, the monkey must fixate while a stimulus is briefly presented in the RF. After a variable delay, the fixation point is extinguished and the monkey saccades to the location where the stimulus appeared. Separate visual and motor bursts are seen in each trial, as well as tonic activity during the memory period.

C.L. Colby, J.-R. Duhamel / Cognitive Brain Research 5 (1996) 105–115

In a task where the monkey has to wait, after seeing a stimulus, before making an eye movement to its location, neurons of Area LIP fire in response to the stimulus, during the delay period, and at the time of the movement.

ANGLE-OF-GAZE EFFECTS IN LIP

Same visual stimulus

Retinotopic RF's

As gaze moves, strength of response varies on direction

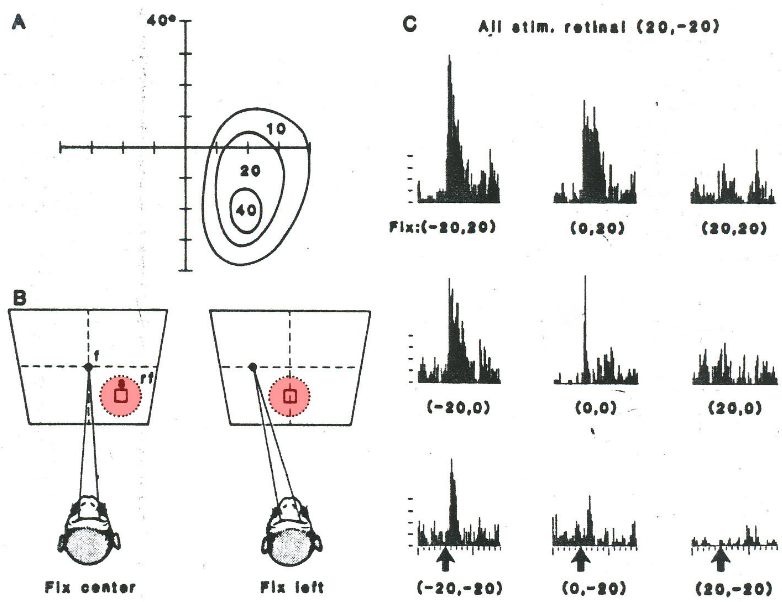


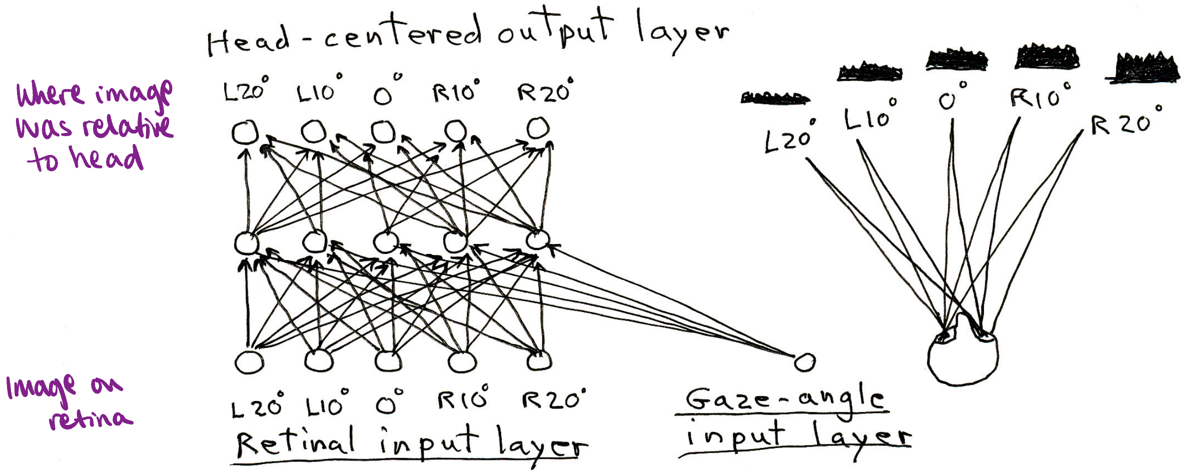
Fig. 1. (A) Receptive field of a neuron plotted in coordinates of visual angle determined with the animal always fixating straight ahead (screen coordinates 0,0). The contours represent the mean increased response rates in spikes per second. (B) Method of determining spatial gain fields of area 7a neurons. The animal fixates point f at different locations on the screen with his head fixed. The stimulus, s, is always presented in the center of the receptive field, rf. (C) Spatial gain field of the cell in (A). The poststimulus histograms are positioned to correspond to the locations of the fixations on the screen at which the responses were recorded for retinotopically identical stimuli presented in the center of the receptive field (histogram ordinate, 25 spikes per division, and abscissa, 100 msec per division; arrows indicate onset of stimulus flash).

Gain field: The visual receptive field is fixed relative to the retina but the gain of the visual response varies as a function of the angle of gaze. The function relating gain to angle of gaze, which is usually planar, is referred to as a gain field.

Andersen et al. Science 230: 456-458 (1985)

Neurons in Area LIP have visual receptive fields that are fixed with respect to the retina. However, the strength of the visual response can vary markedly as a function of the angle of gaze.

Zipser and Andersen (Nature 331: 679-684, 1988) trained a simulated neural network to signal (at its output layer) the location of a visual stimulus relative to the head. Its input layers signaled the location of the stimulus on the retina and the angle of the eyes in the head. After training, they tested the properties of units in the hidden layer. These units had visual receptive fields fixed to the retina and gave visual responses which varied in strength as a function of the angle of gaze — features shared with neurons in Area LIP. The authors argued, given this evidence, that LIP may be an intermediate stage between areas representing the locations of things relative to the retina & areas representing head-centered locations.



Details for those who are interested.

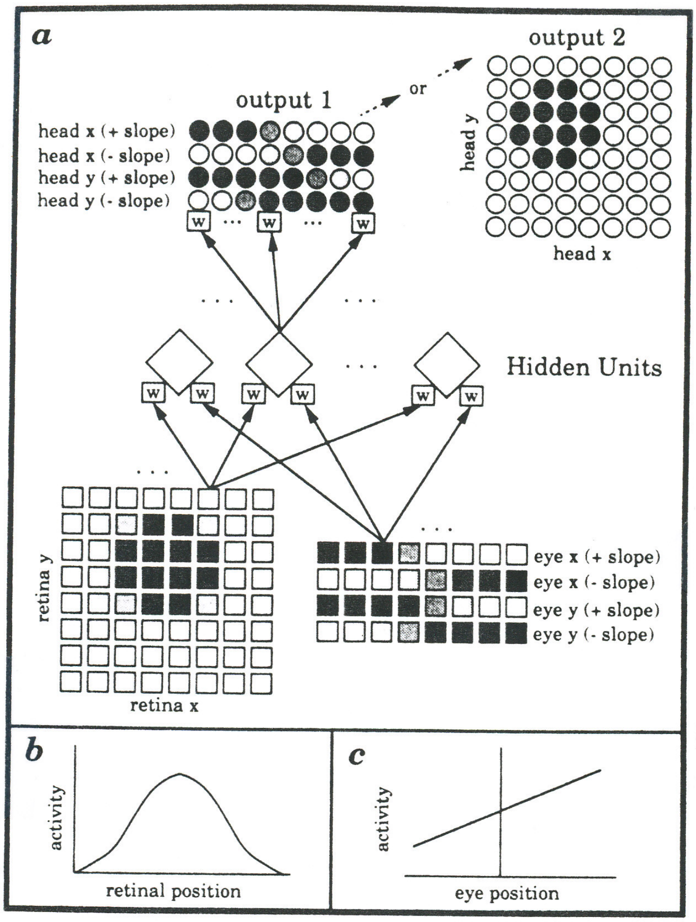


Figure 2. *a,* Structure of the Mixed $A_{R\text{-}P}$ network. The network is composed of three layers of computing units: input units (encoding retinal location of stimulus and eye position), hidden units, and output units (encoding head-centered location of the visual stimulus). Retinal position of the visual stimulus is encoded topographically by an 8 × 8 array of input units, each with a gaussian receptive field (described in *b*). The remaining 32 input units code for eye position in a linear fashion (see *c*), with two groups of eight units encoding horizontal gaze angle (with positive and negative slopes), and two groups of eight units for vertical angle. Units in the output layer code for head-centered coordinates in a monotonic format (*output 1*) similar to the eye position input, or in a gaussian format (*output 2*) similar to the retinal input. The hidden units are binary stochastic elements, while the output units are deterministic logistic elements (see Fig. 3). Shading is proportional to unit activity in the input and output layers. Connection weights are indicated by *w*. *b,* Angle-coding function of the retinal input units. Each unit's activity level is a gaussian function of the retinotopic *x*- and *y*-coordinates of the visual stimulus, one $1/e$ width of 15°, and spaced 10° apart from that of its neighboring units. *c,* Angle-coding function for the eye position units. Each unit codes for the *x* or *y* eye position linearly. The slopes and intercepts for each unit were assigned randomly within ranges observed for area 7a neurons.

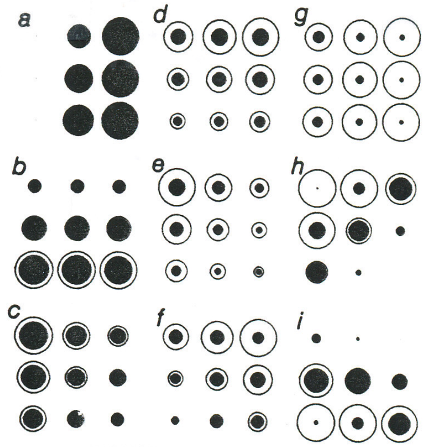
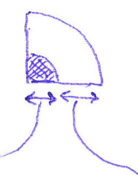


Fig. 6 Hidden unit spatial gain fields generated by the model network. Fields *a–f* were generated using the monotonic format output; the rest used the gaussian format output.



Increase elicited by visual stimulus in RF

Prestimulus Baseline (may be influenced by gaze angle)

Zipser & Andersen
Nature 331: 679–684
(1988)

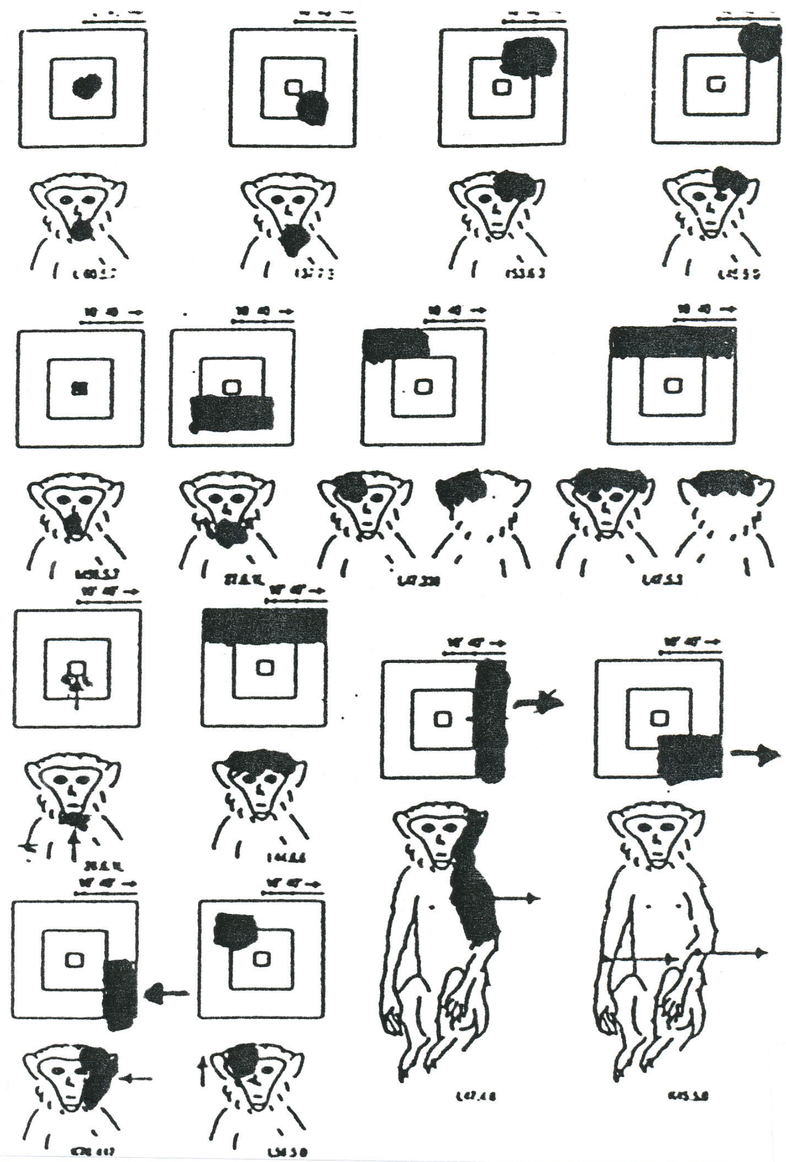
VIP

Visual & somatosensory RFs

Some neurons in Area VIP respond to both cutaneous and visual stimulation and have matching bimodal receptive fields defined with respect to the body.

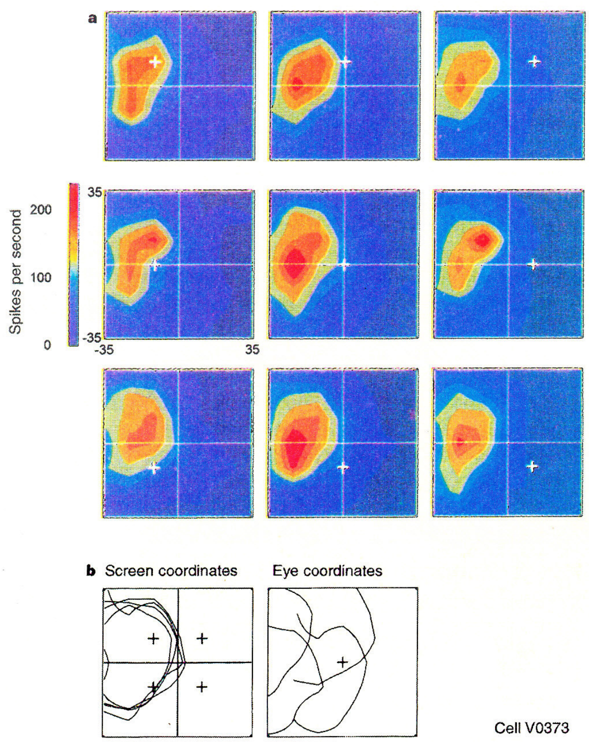
In many VIP neurons, congruence is maintained

Visual RF shifts on retina to correspond w/ cutaneous RF



Duhamel et al. in __Brain & Space__, J. Paillard, ed., Oxford Univ. Press, 1991, pp. 223-236

Some visually responsive neurons in Area VIP have receptive fields that remain at a fixed location on the screen even as the monkey's angle of gaze changes.



Similar to output layer in Zipser model

Figure 2 Single-neuron data for visual receptive field mappings in which the RF remains in the same spatial location irrespective of eye position. The RF was mapped with a white bar moving at 100 deg s^{-1} for brief intervals in the neuron's preferred direction. **a**, Colour-coded maps of the RF were constructed for each fixation position. Contour maps represent isofrequency intervals computed from linearly interpolated data matrices. Maps are displayed in screen coordinates. The small white crosses correspond to the eye position during visual stimulation; the intersection of the light horizontal and vertical lines corresponds to the straight-ahead direction in space. **b**, Contour plots for the top left, top right, bottom left and bottom right RF maps show the stimulation region from which firing rates above 50% of peak discharge were obtained. The left graph superimposes the four RF maps as they appear in screen coordinates (as in the colour-coded plots); the right graph represents the same maps but reframed in eye coordinates (relative to the fovea).

J.R. Duhamel et al.
Nature 389: 845–848 (1997)

MIP

"parietal reach region"

Planning of reach

Neurons in Area MIP fire specifically during visually guided reaches, as opposed to visually guided saccadic eye movements.

either eye movement or arm movement

memory-guided Saccade task & reaches

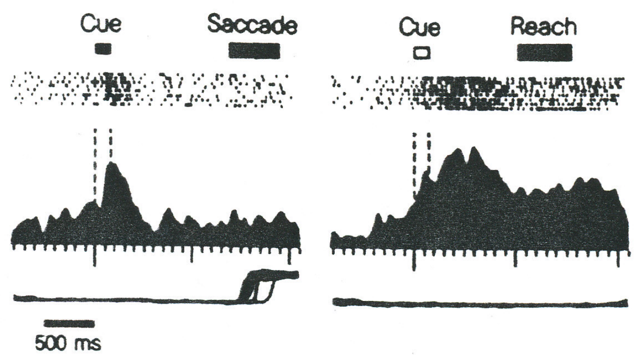


Figure 1 Responses of a reach-specific neuron in the delayed-saccade (left) and delayed-reach (right) tasks. Each panel shows timing of peripheral flash ('Cue': red flashes indicated by filled bars, green flashes by open bars) and response ('Saccade' or 'Reach'); eight rows of rasters corresponding to every third action potential recorded during each of eight trials; a spike density histogram of neuronal activity, generated by convolution with a triangular kernel[27] aligned on cue presentation, with cue onset and offset indicated by dashed lines; and eight overlaid traces showing vertical eye position. Neuronal responses in the cue interval (50 ms before to 150 ms after cue offset) were nonspecific. However, during the delay interval (150–600 ms), firing depended specifically on motor intent.

Snyder et al.
Nature 386: 167-170
(1997)

neurons in MIP encode reach direction w/ respect to retina-centered reference frame (not body-centered)

Sensitive to gaze or reach direction? Kinda neither

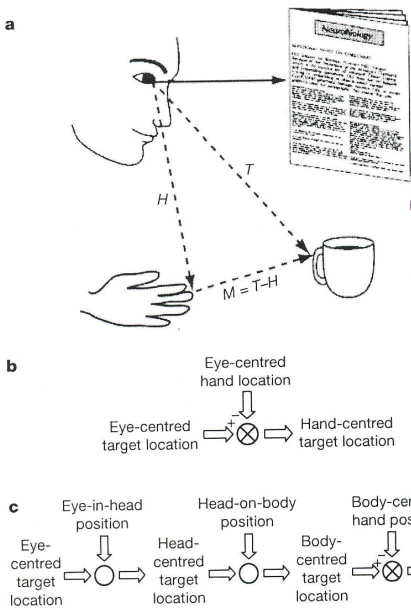
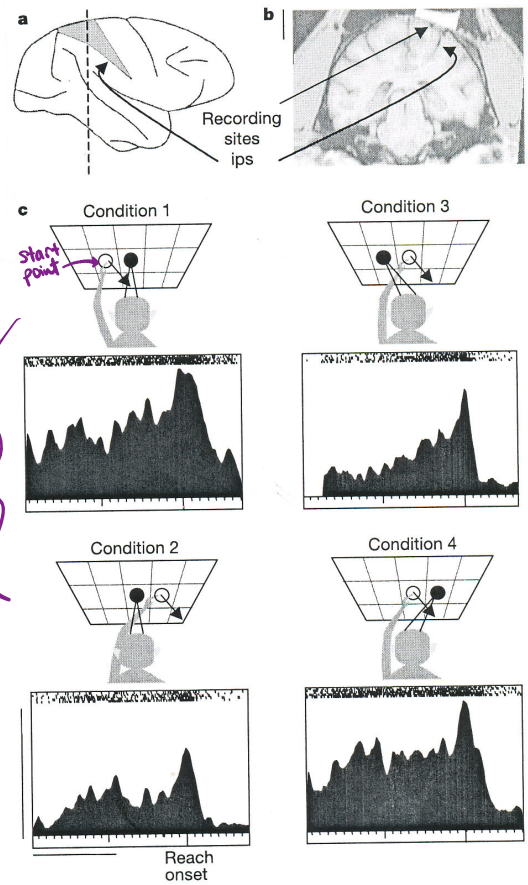


Figure 1 Visuomotor transformation schemes. **a**, Example of reaching for a cup while fixating on a newspaper. The position of the cup is initially represented in the brain in terms of its location on the peripheral retina (*T*). To reach for the cup, its position with respect to the hand must be known (*M*). This information could be acquired by directly subtracting hand position (*H*) from target position (*T*) in eye coordinates (**a**, **b**), or by gradually transforming the position of the target from eye- to body-centred coordinates, and subtracting the body-centred position of the hand (**c**). (Adapted from ref. 29.)

same gaze angle



same reach trajectory

Figure 2 Responses of a single neuron from area 5. **a**, Diagram of a macaque monkey brain showing the location of area 5 (shaded region) and the approximate location of the magnetic resonance image (MRI) section in **b**. ips, intraparietal sulcus. **b**, Coronal T1-weighted MRI section through the approximate centre of the area 5 recording sites. Scale bar, 1 cm. **c**, Spike density histograms of the activity of one area 5 neuron for the same planned movement vector (down and to the right) in each of four experimental conditions. Vertical scale bar, 140 spikes s^{-1}; horizontal scale bar, 1 s.

Evidence for the involvement of MIP neurons in visuomotor guidance: they encode the location of a reach target relative to an eye-centered reference frame.

Buneo et al.
Nature 416:632-636 (2002)

AIP

lies behind cortex w/ somatosensory rep of hand

Neurons in Area AIP fire during grasping of specific objects (Neuron A) or in conjunction with seeing them (Neuron B) or both (Neuron C).

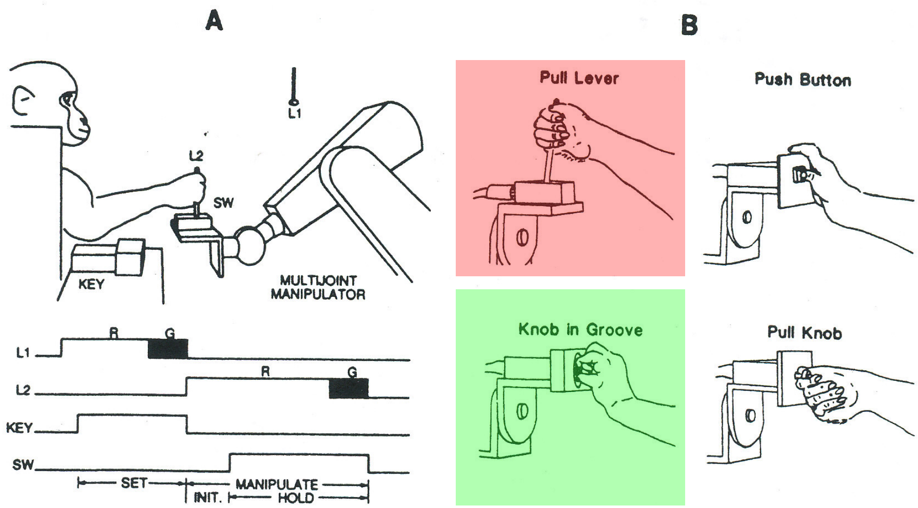
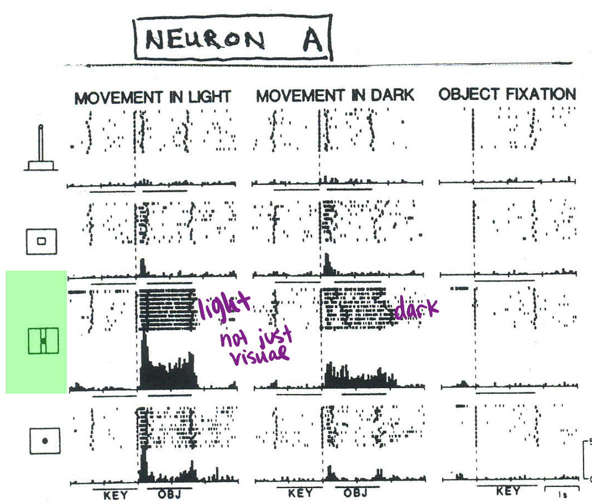
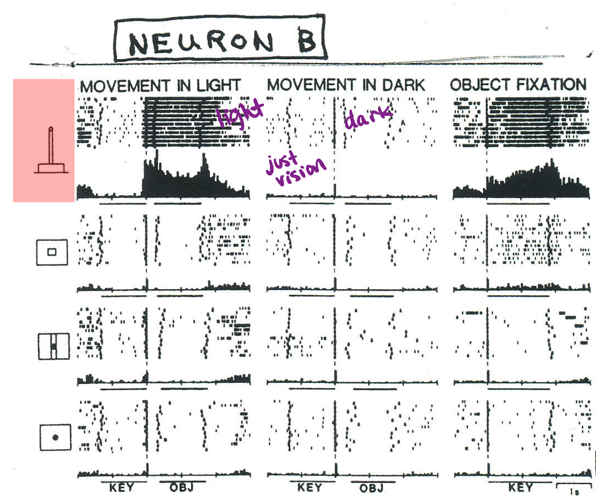
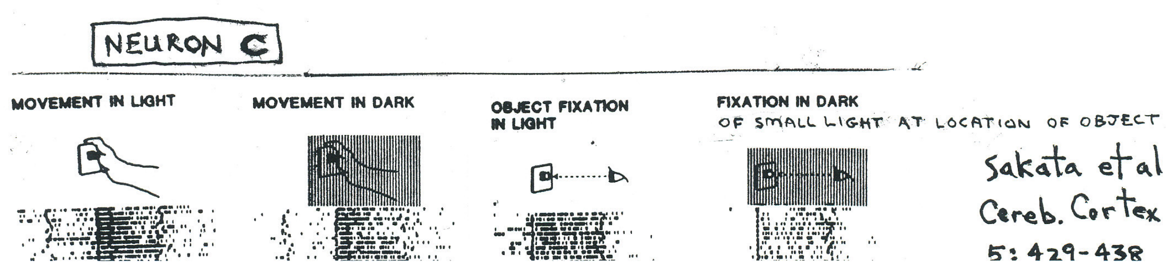


Figure 1. *A*, The experimental setup and time sequence of manipulation task. *L1*, fixation spot; *L2*, a small LED attached on top of each object; *KEY*, an anchor key at lap level; *SW*, a microswitch connected to the object. In the time sequence chart, upward deflection of traces in both L1 and L2 indicates red (*R*) or green (*G*; *hatched area*) LED color. Upward deflection of traces in KEY and SW denotes the time during which the key was pressed and the switch was held on. *B*, The four types of objects for manipulation and the shape of monkey's hand. See further details in the text.







Sakata et al.
Cereb. Cortex
5: 429-438

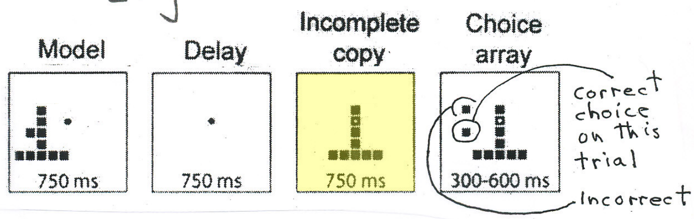
Transition from visual representations of objects → generation of grasp movement

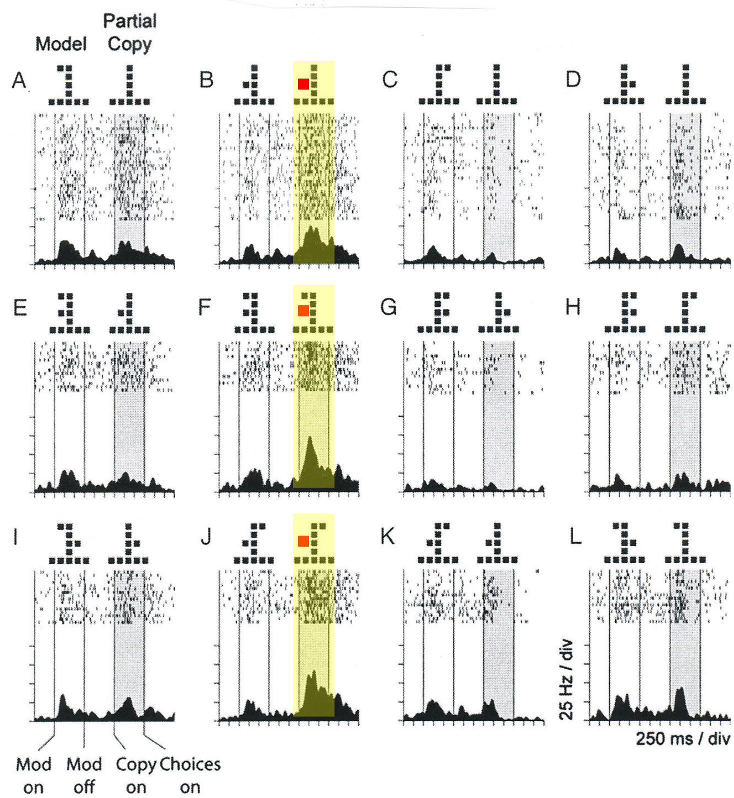
7a

Spatial cognition?

In monkeys trained to view an image ("model") briefly and then, after a delay, to view another image formed by removing a piece from the model ("incomplete copy"), and to report by choosing a dot where the piece had been taken away, neurons in parietal area 7a signaled the location of the missing piece relative to the object. This is evidence for involvement in visuospatial cognition as distinct from visuomotor guidance

Chafee et al.
Cerebral Cortex
15: 1393 (2005)





imagining a part ↓ & ← firing is strong

fires differently
Location relative to reference object in mind

Sensitive to imagined location

Conclusion:
carrying spatial cognitive, not just sensorimotor signal

Figure 3. Example of a neuron in area 7a in which activity during the copy period reflected the location of the missing square. (*A–L*) Trials are segregated according to the combination of model and incomplete copy objects that were presented, as illustrated above each raster. The time of the sequential events in the construction trial are indicated by the four vertical lines through each raster (excluding the y axis) which indicate (left to right) the onset of the model object, the offset of the model object (beginning of the delay period), onset of the copy object, and onset of the choice array, as labeled in (*L*). The incomplete copy period is indicated by the vertical bar of gray shading. At the bottom of each raster a spike density function ($\sigma = 20$ ms) illustrates mean neural activity over time. Divisions indicate increments of 25 Hz on the vertical axis and 250 ms on the horizontal axis. (*B, F, J*) Neural activity evoked by the copy object is a function of the location of the missing square relative to the preceding model. Activity increases on trials in which the missing square is located at the lower left position within the object (compare model and copy objects). (*A–D*) Neural activity varied with the location of the missing square when the visual form of the copy object did not vary. On these trials, models consisted of the object frame plus a single square, and consequently the copy object consisted of the object frame only in every case.