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19 ABSTRACT (Continue on reverse if necessary and identify by block number)
The research supported by this grant focused on the structure of high-level visual processing. Five types of research were conducted: (1) We performed case studies of individual brain-damaged patients. We found evidence that curved edges are processed separately from straight edges and that location information sometimes can be used to encode some characteristics of shape. (2) We tested groups of brain-damaged patients with specific types of lesions. We found evidence that metric information may be used to encode spatial categories (such as above/below), and that imagery may involve some structures that are intact even when the visual field is disrupted. (3) We developed a computerized visual/spatial test battery, and administered it to a group of 19 brain-damaged patients. The results indicate that most of the visual/spatial abilities we examined can be impaired independently, suggesting that at least some distinct subsystems carry out each ability. (4) We implemented computer models and found support for the distinction between subsystems that compute two distinct kinds of spatial relations (metric and category). (5) Some of the tasks we developed to study deficits in brain-damaged patients were used to study the visual-spatial abilities of air force pilots; we found that pilots are particularly good at mental rotation and encoding metric distance information.

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FINAL TECHNICAL REPORT

Neuropsychological Components of Object Identification

AFOSR 91-0100

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Harvard University

Sixteen publications were supported by this grant over the past three years. I will begin by summarizing the content of each, and then will turn to additional work that is not yet completed. Following this, I will describe a test battery that has been developed in the course of this work. Finally, I will list the students and post-doctoral fellows whose research has been supported in part by this grant.

Papers in Refereed Journals

1. Kosslyn, S. M. (1991). Visual cognition: A cognitive neuroscience approach. *Neurology Chronicle, 1,* 1-4.

This article provided a conceptual framework for understanding visual cognition. At least since the nineteenth century, there has been a tension between theorists who posit that distinct brain loci produce specific behaviors and theorists who posit that the brain works as a single, holistic organ. This debate now appears to be resolved. Luria, Geschwind, and many others note that any complex behavior, such as language, memory, or perception, depends on numerous brain loci; however, each of these regions appears to perform a limited number of types of operations. Cognitive functions are not carried out in specific loci, but rather arise through the joint action of a host of loci working together, with each having a specific role. Thus, at a coarse level of analysis, the brain works as a single organ, but at a finer level, specific operations are localized. Although this resolution of the debate is now widely accepted, it has not been clear how to characterize the functions that are localized to distinct places in the brain. The late David Marr argued that these components are best thought of as performing distinct "computations." A computation is, roughly, a mapping of an input that specifies information to an output that specifies information, where the relation between the input and output can be described by a function. Marr offered a method for generating hypotheses about the nature of such computations: first, consider carefully how a particular system allows us to behave (e.g., the kinds of things we can see, discriminations we can make, and so on), and then analyze how one could build a machine that behaves that way. But not just any machine is of interest; we want to know how one could build a machine that has the structure (neuroanatomy) and dynamic properties (neurophysiology) of the brain. In this article I illustrate how this *cognitive neuroscience* approach is leading us to conceptualize visual perception. I focus here on the "higher" levels of processing, which follow retinal and low-level cortical processes that detect edges and the like. I summarize two examples of the approach.

2. Kosslyn, S. M., Chabris, C. F., Marsolek, C. J., & Koenig, O. (1992). Categorical versus coordinate spatial representations: Computational analyses and computer simulations. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 562-577.

Four computer simulation experiments provide support for the distinction between categorical and coordinate spatial relations representations. Parallel-distributed-processing networks were programmed to evaluate whether a dot was above or below a bar (a categorical task) or was within 4 elements of it (a coordinate task; elements were considered at the finest level of grain). In the first experiment, networks that were split so that only half of the hidden units provided information for each judgment performed the mapping more effectively than networks that were not split. In contrast, the opposite result was found when networks were required to make two coordinate judgments. In the second experiment, both computations were more difficult when the dot locations were restricted to a smaller range, mirroring the corresponding findings with human subjects. In the third experiment, networks with relatively small "receptive fields" performed the categorical task better than networks with relatively large receptive fields, but vice versa for the coordinate task; these results suggested a possible basis for observed lateralization of the two kinds of processing. Finally, in the fourth experiment, the effect of contrast on the hemisphere difference could be accounted for if larger numbers of input units produce useful output with greater stimulus contrast.

3. Marsolek, C. J., Kosslyn, S. M., & Squire, L. R. (1992). Form-specific visual priming in the right cerebral hemisphere. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(3), 492-508.

The results of four experiments indicate that both within-modality and case-specific visual priming for words are greater when test stimuli are presented to the right cerebral hemisphere. In contrast, neither within-modality nor case-specific explicit memory for words is greater when stimuli are presented to the right hemisphere. Priming is measured using the word stem completion task, and explicit memory is measured using word stem cued recall. In both cases, subjects first rate how much they like or dislike words, and then word stems are presented briefly to the right hemisphere (in the left visual field) or to the left hemisphere (in the right visual field). The results suggest that at least two separate systems encode the visual word form representations that produce priming. The system that is more effective in the right hemisphere is better at representing form-specific information, whereas another system that is equally effective in both hemispheres does not distinguish among distinct instances of word forms. The implications of these findings are described in relation to results of recent studies using positron emission tomography and to current issues surrounding priming.

4. Kosslyn, S. M., & Intriligator, J. R. (1992). Is cognitive neuropsychology plausible? The perils of sitting on a one-legged stool. *Journal of Cognitive Neuroscience*, 4(1), 96-106.

This is a conceptual/methodological analysis in which we consider what can, and cannot, be inferred about the workings of a normal system on the basis of behavioral deficits that occur following brain damage. We distinguish between *strong* and *weak* cognitive neuropsychology, with the former attempting to provide direct insights into the nature of information processing and the latter having the more modest goal of providing constraints on such theories. We argue that strong cognitive neuropsychology, although possible, is unlikely to succeed and that researchers will fare better by combining behavioral, computational, and neural investigations. Arguments offered by Caramazza (1992) in defense of strong neuropsychology are analyzed, and examples are offered to illustrate the power of alternative points of view.

5. Cave, C. B., & Kosslyn, S. M. (in press). The role of parts and spatial relations in object identification. *Perception,*

These experiments were designed to investigate the role of parts and their spatial relations in object identification. At the most general level, two important results were obtained. First, proper spatial relations among components of an object are critical for easy identification. When parts were scrambled on the page, naming times and error rates increased. And second, the way an object is divided into parts (parsed) affects identification only under the most impoverished viewing conditions. When subjects had as little as 1 s (and sometimes as little as 200 ms) to view an object, the way objects were divided into parts had no effect on naming times or accuracy. There was no hint of an interaction between type of parse and how parts were arranged on the page. This pattern of effects supports theories that suggest that objects typically are recognized without being parsed into parts. Instead, the findings are in agreement with theories suggesting that object features (not specifically related to parts) are matched directly with such features stored in long-term memory, with the constraint that the features of a single object are seen from a single viewpoint. The results present a strong challenge to theories such as Biederman's (1987) "recognition by components" theory.

6. Dror, I. E., Kosslyn, S. M., & Waag, W. L. (in press). Visual-spatial abilities of pilots. *Journal of Applied Psychology,*

Air Force pilots and control subjects participated in five experiments, each of which assessed a different type of visual-spatial ability. Although pilots judged metric spatial relations better than non-pilots, they did not judge categorical spatial relations better than the non-pilots. Pilots mentally rotated objects better than non-pilots, but pilots did not extrapolate motion, scan images, or extract visual features from objects obscured by visual noise better than non-pilots. The results imply that efficient use of specific processing subsystems is especially important for, and characteristic of, pilots. The possible neuropsychological bases for the enhanced abilities and their susceptibility to change are discussed.

7. Brown, H. D., & Kosslyn, S. M. (in press). Cerebral lateralization. *Current Opinion in Neurobiology,*

Simple dichotomies are unlikely to account for patterns of cerebral lateralization; rather, the literature suggests that hemispheric differences will be understood in terms of relatively specific principles that extend over limited domains. For visual perception and mental imagery, the left hemisphere appears to be relatively better than the right at encoding component parts, representing visual categories, and encoding categorical spatial relations (such as "above/below"); in contrast, the right hemisphere appears to be relatively better than the left at encoding overall patterns, representing specific instances, and encoding coordinate metric spatial relations. Computer simulation models suggest that all of these differences could arise from a bias for the left hemisphere to process outputs from neurons with small, relatively nonoverlapping receptive fields, and for the right hemisphere to process outputs from neurons with large, overlapping receptive fields.

8. Kosslyn, S. M., Daly, P. F., McPeek, R. M., Alpert, N. M., & Caviness, V. S. (accepted with revisions). Using locations to store shape: An indirect effect of a lesion. *Cerebral Cortex,*

This study had three general points: First, it examined possible visual consequences of frontal lesions. A patient with focal damage to the subcortical regions of the left frontal lobe, and a small amount of damage near Broca's area, was predicted to have impaired brain function in posterior regions that are anatomically connected to the damaged site. Second, it showed the utility of using positron emission tomography (PET) in conjunction with magnetic resonance imaging (MRI) to diagnose "functional lesions." PET revealed reduced metabolism in posterior cortical loci that are innervated by fibers from the damaged region. Some of the affected areas are hypothesized to be involved in visual functions, specifically the encoding of lines and edges. Third, the results of a series of tests suggested that the patient encoded shapes as sets of filled locations, which allowed him to use intact processes subserved by brain areas that were not affected by the damage. The results were interpreted in terms of functions of the intact dorsal system, which encodes spatial properties, being used instead of impaired functions of the ventral system, which encodes object-properties. The data were best explained if the lesion slowed processing in the ventral system in some conditions, allowing the dorsal system to produce a response more quickly than the ventral system.

9. Kosslyn, S. M., & Gould, S. J. (accepted with revision). On the goals and limits of evolutionary psychology: A critique of Anderson. *Psychological Review,*

Evolutionary theory offers one source of motivation for psychological theories. This article uses Anderson's method of "rational analysis" as a springboard for examining proper and improper uses of evolutionary theory in psychology. The idea that all features of an organism evolved to serve their present purposes is criticized, and the claim that evolution has optimized complex processes is shown to be highly implausible. The article concludes with suggestions about ways in which evolutionary theory can be used to further psychological theorizing. Although the article was tentatively accepted pending revision, the revisions will probably be so major that it will require another round of reviewing.

10. Kosslyn, S. M., Hamilton, S. E., & Bernstein, J. H. (submitted). The perception of curvature can be selectively disrupted in prosopagnosia. *Brain and Cognition,*

A brain-damaged patient with prosopagnosia had a selective deficit for encoding curved lines and curved contours. The patient and a group of age- and education-matched control subjects evaluated curved and straight versions of different sorts of stimuli in different tasks; the patient consistently required more time for curved than for straight stimuli, relative to the control subjects. Specifically, he had a deficit when he compared curved lines that were simultaneously visible, when he compared curved lines with those previously seen, when he examined a curved shape to determine whether an X was on or off the shape, when he decided whether a word named a degraded picture of a curved object, and when he read curved script. Implications of these findings for the role of "end stopped" cells in visual cortex are discussed.

11. Jacobs, R. A., & Kosslyn, S. M. (submitted). Encoding shape and spatial relations: The role of receptive field size in coordinating complementary representations. *Cognitive Science,*

An effective functional architecture will facilitate interactions among subsystems that are often used together. Computer simulations showed that differences in receptive field sizes can promote such organization. Specifically, when input was filtered through relatively small nonoverlapping receptive fields, networks learned to categorize shapes or spatial relations relatively quickly; in contrast, when input was filtered through relatively large overlapping receptive fields, networks learned to encode specific shape exemplars or metric spatial relations relatively quickly. Moreover, when the receptive field sizes were allowed to adapt during learning, networks developed smaller receptive fields when they were trained to categorize shapes or spatial relations, and developed larger receptive fields when they were trained to encode specific exemplars or metric distances. In addition, when pairs of networks were constrained to use input from the same type of receptive fields, networks learned a task faster when they were paired with networks that were trained to perform a similar type of task. Finally, using a novel modular architecture, networks were not pre-assigned a task, but rather competed to perform the different tasks. Networks with small nonoverlapping receptive fields tended to win the competition for categorical tasks whereas networks with overlapping large receptive fields tend to win the competition for exemplar/metric tasks

Books or Chapters Published

1. Kosslyn, S. M., & Koenig, O. (1992). *Wet mind: The New Cognitive Neuroscience.* New York: The Free Press.

This book reviews the conceptual foundations of cognitive neuroscience, and key findings and theories of perception, visual cognition, reading, language, motor control, and memory. In so doing, it develops a theory of the functional architecture of the information processing that underlies these abilities.

2. Kosslyn, S. M., & Andersen, R. A. (Eds.) (1992). *Frontiers in cognitive neuroscience.* Cambridge, MA: MIT Press.

This book collects what we believed were the most stimulating papers in cognitive neuroscience. It is organized into sections based on content, which ranged from perception to cognition. An introduction placed the field in context, and individual section introductions pointed out bridges between the various contributions.

3. Kosslyn, S. M. (in press). *Image and brain: The resolution of the imagery debate.* Cambridge, MA: MIT Press.

This book summarizes the last 20 years of research in my laboratory. It is been reviewed by six experts in different fields (the book is highly interdisciplinary), and is currently in the process of being revised.

4. Kosslyn, S. M., & Jacobs, R. A. (in press). Encoding shape and spatial relations: A simple mechanism for coordinating complementary representations. In V. Honavar and L. Uhr (Eds.), *Integrating Symbol Processors and Connectionist Networks for Artificial Intelligence,*

This chapter summarizes much of the work reported in the Jacobs & Kosslyn paper (described above); the Jacobs & Kosslyn paper is a later report. The present chapter puts the research in a broader psychological framework, whereas the paper is more technical and less psychologically oriented.

5. Kosslyn, S. M., & Shin, L. M. (in press). Visual mental images in the brain: Current issues. In M. J. Farah, & G. Ratcliff (Ed.), *The neuropsychology of high-level vision: Collected tutorial essays.* Hillsdale, NJ: Lawrence Erlbaum.

This chapter attempts to delineate the major current issues about the brain mechanisms that underlie imagery; in so doing, we review findings that have a direct bearing on these issues. We concentrate on the aspects of imagery that allow us to use it to recall information and to reason about spatial properties. We focus on four abilities: First, we are able to "inspect" patterns in images; second, we are able to form images in the first place, adding additional objects to the imaged scene; third, we can mentally transform the scene, imagining objects shifting and turning in various ways; fourth, we are able to retain the image while we add new objects and manipulate them in various ways. We consider key issues about each of these abilities, and for each we summarize recent findings that bear on the nature of the neural mechanisms that underlie the ability.

Papers in Preparation

1. Kosslyn, S. M., Andersen, A. K., Hamilton, S. E., & Livingstone, M. J. Hemispheric differences in sizes of receptive fields?

Subjects judged whether two successive line segments had the same orientation. The pairs were lateralized, and the distance between the segments was varied. Subjects judged segments that were relatively far apart more quickly when they were presented in the left visual field, and hence seen initially by the right hemisphere; in contrast, there was a trend for the opposite result when subjects judged segments that were relatively close together. These results were predicted by the theory that the right hemisphere receives more input from neurons with relatively large receptive fields whereas the left hemisphere receives more input from neurons with relatively small receptive fields.

2. Brown, H. D., & Kosslyn, S. M. Hemispheric differences in visual object processing: part/whole relations?

As is evident in the literature, the right hemisphere does not always compute the global form of an object more effectively than the left hemisphere (LH), nor does the left hemisphere always compute smaller details more effectively than the right hemisphere (RH). In our experiments, the subjects evaluated letter stimuli in the same way when the stimuli were shown initially to the LH or the RH under certain conditions, even when the general features of these stimuli were matched to those of the pictures--which did elicit hemispheric asymmetries in the same conditions. We conclude that structural differences do not underlie the hemispheric differences in visual processing; rather, the hemispheres differ in their predilections towards certain types of processing. Moreover, the results suggest that these differences occur because the subjects are led to attend to different characteristics of the stimuli. We hypothesize that the hemispheres differ in their ability to monitor outputs from different-sized receptive fields of low-level neurons. In terms of Kosslyn, Flynn, Amsterdam and Wang's (1990) model, hemispheric asymmetries in visual processing occur because the hemispheres allocate attention differently, which changes the input to the preprocessing subsystems. The process of allocating attention probably occurs via top-down mechanisms, which seek information that will be useful for performing a task (see Kosslyn & Koenig, 1992, chapter 3). Thus, task parameters and stimulus characteristics can affect how attention is allocated to different sized receptive fields.

3. Kosslyn, S. M., Mijovic, D., Shin, L. M., & Wray, S. H. Visual hemianopia and visual mental imagery.

A series of brain-damaged patients with homonymous hemianopia were given imagery tasks that required estimating the "visual" angle subtended by imaged objects. The results revealed that the angle subtended in imagery was not always predicted by the maximum angle subtended by objects in the intact visual field. Depending on the type of lesion, the angle subtended by imagery was intact or was drastically reduced. These data are still being analyzed.

4. Kosslyn, S.M., Shin, L. M., Chabris, C.F., Mijovic, D., & Wray, S. H. Categorical and coordinate spatial relations encoding following brain damage.

Twenty six brain-damaged patients have been asked to determine whether a dot is above/below, inside/outside, on/off, or left/right of a pattern on a screen; they have also been asked to decide whether the dot is within .5 in of the pattern. The prediction is that the categorical tasks will be disrupted more following damage to the left hemisphere than to the right hemisphere. Preliminary analyses suggest that this prediction will be disconfirmed; it appears that right-hemisphere damage is more disruptive, even if these more linguistic spatial relations representations. However, this result may be a consequence of unilateral visual neglect. The data are still being analyzed, and we probably will test more patients with right parietal lesions who do not have neglect.

5. Kosslyn, S.M., Shin, L. M., Chabris, C.F., Hamilton, S.E.., & Wray, S. H. Double dissociations among visual-spatial abilities.

This paper will describe the results of testing 19 subjects on the test battery summarized below. We find that the vast majority of tests exhibit double dissociations: one patient can be impaired on Test A more than on Test B, but vice versa for another patient. We have examined these results by comparing them to Monte Carlo computer simulations. We currently are analyzing the data using various multivariate techniques, which are not always producing the expected results (dimensions that correspond to distinct subsystems).

Test Battery

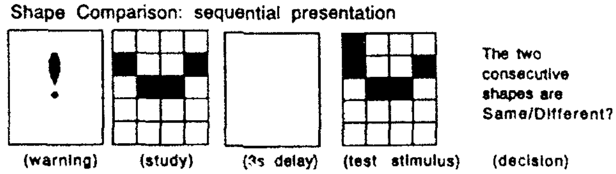
In the course of testing patients, we have developed a battery of tests. These tests appear to have general use. For example, Dror, Kosslyn & Waag (see above) used some of them to test visual/spatial abilities in air force pilots. The tests are summarized below.

Filter tasks

1. *Visual buffer.* When we administer the battery, we first provide a full neuro-ophthamic examination, which documents visual acuity at a distance and nearby, color vision, stereopsis, visual field to kinetic and static targets, pupil reflexes, ocular motility, and tests for diplopia. The critical tests, however, are visual acuity and color vision, which are easily administered using standardized materials.

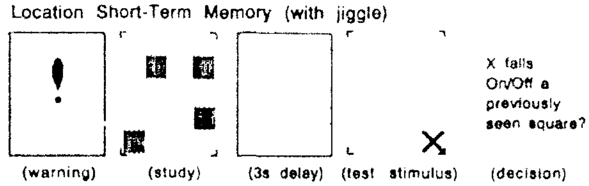
2. *Shape comparison: Sequential presentation.* In all tasks, each trial is signaled by a warning symbol (an exclamation mark). In this task, the subject then sees a 4 x 5 grid with some of the cells blackened; cells are blackened to form either 1, 2, or 3 perceptual units (a 3-unit pattern is illustrated below). The subject studies the pattern until he or she has memorized it, and then presses the space bar. The pattern is removed and there is a 3 s delay, at which point another pattern is presented. On half the trials, the second pattern is identical to the first, and on half it has been modified. The subject has only to indicate whether the second pattern is the same or different from the first. The *manipulation* here is the number of perceptual units. By varying the number of perceptual units, we tax the subsystems that encode and store the first pattern and that encode the second and compare it to the representation of the first. The *score* here is the amount of increase in time or errors with more perceptual units.

Shape Comparison: sequential presentation

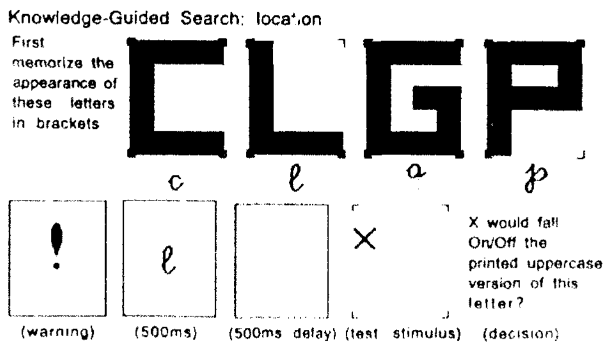


3. *Location short-term memory.* The subject sees either 2 or 4 gray squares (which are exactly the size of the cells in a 4 x 5 grid); half the cells are at the top half of the display and half are at the bottom, and half are on the left and half are on the right; otherwise, placement is random. The subject studies the display, memorizing the location of the squares, and then presses the space bar. The squares are removed for 3 s, and then an X appears. The subject decides whether the X is in a location previously occupied by a square. The test display frame is moved slightly to the left, right, up, or down (the equivalent of one row or column) so that the subject cannot simply remember locations on the screen, but must remember locations relative to the frame surrounding the stimuli. The *manipulation* here is the number of *squares, and we expect increased times and errors with additional perceptual* units if any of the subsystems involved in representing location are awry. The *score* is the increase in time or errors for 2 vs. 4 squares. We assume that the spatiotopic mapping subsystem must be used because the display is jiggled, and the categorical spatial relations encoding subsystem is used because some

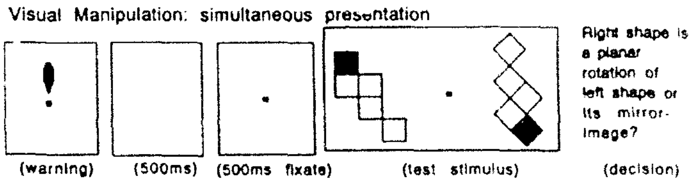
squares are in corners or other easily-categorized locations, and the coordinate spatial relations encoding subsystem is used because some squares must be memorized in terms of metric distance within the field.



4. *Knowledge-guided search: location*. The subject first studies block letters as they appear on the screen, also noting the lower case letters associated with each. To ensure learning, a lower case letter is either paired with the correct block letter or another block letter, and the subject simply indicates whether the pairing is correct. This task is repeated until the subject responds correctly to all stimuli or until there has been no increased performance for two consecutive runs (at which point we conclude that there is a problem in associative memory if we have found no problem in shape encoding in the first task). Following this, the actual testing phase begins. The subject sees a lower case letter for .5 s, there is a .5 s delay, and then the patient sees an X mark; he or she is asked whether the X would fall on the block letter if were in the field as it previously appeared. This task requires accessing a stored representation of the block letter, which Kosslyn, Cave, Provost & Von Gierke (1988) showed was done via accessing individual segments of the letter sequentially. For some locations of the X marks, categorical spatial relations are adequate (e.g., when the x is next to the boundary of the field) for specifying the location of the segment (e.g., "next to the edge"). For others (in the interior of the field) coordinate relations are necessary (for a more detailed argument why different types of relations are needed, see Kosslyn, 1988). Thus, this task taps one's ability to use the lookup subsystems to access stored information. In addition, it also taps one's ability to use stored information to shift attention to the correct location. The *manipulation* here is the complexity of the figure. Kosslyn et al. (1988) found that more time was taken in this task for letters with more segments. Thus, the *score* is the increase in time or errors for X probes for relatively complex letters (e.g., G. P) compared to relatively simple ones (e.g., C, L).



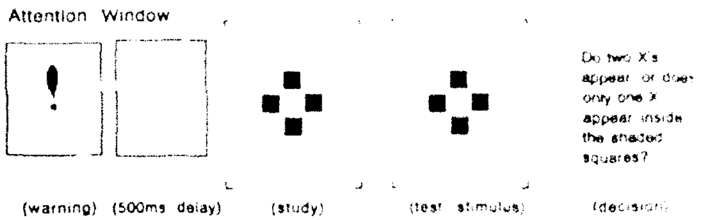
5. *Visual manipulation: Simultaneous presentation.* Subjects fixate and then see two copies of an angular figure, one to either side of fixation. The figure is formed by selecting 4 or 5 connected cells in a 4 x 5 grid and eliminating the remaining cells of the grid. The left figure is oriented vertically, and the right is tilted one of 6 different angles; the top cell of both stimuli is filled in, making it easy to discover how the right figure is tilted. The subject is simply to decide whether the two versions are identical, except for tilt, or are mirror-reversals. The *manipulation* is the amount of tilt. Shepard & Cooper (1982) review much data indicating that the greater the angular disparity between the stimuli in tnis task, the more "mental rotation" is required before they can be compared. These data can be explained if we posit a (very coarsely characterized) subsystem that shifts representations in the visual buffer. Kosslyn (1987) develops this idea in some detail, and argues that the spatial relations encoding and lookup subsystems must be involved in this process, if only to use stored information to keep shapes properly aligned. Thus, this is a complex task, and the results are most interesting if there are no deficits on the previous filter tasks. The *score* is the slope of the increase in times and errors with increasing angular disparity.



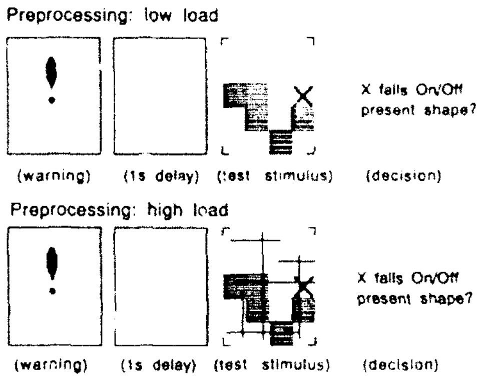
Object-Properties Tasks

The following tasks are designed to diagnose specific deficits in the "object processing" system, which is located in cortex in part in the inferior temporal lobe (see Ungerleider & Mishkin, 1982). .

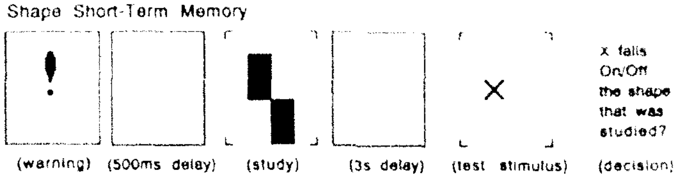
1. *Attention window.* The subject could have difficulty encoding complex patterns because he or she cannot attend to the entire pattern at once. This task is designed to assess the subject's ability to attend to regions subtending different visual angles. The subject sees 4 gray squares, which form a symmetrical pattern around the center of the field. After studying them, he or she presses the space bar and two X marks appear on the pattern. The question is, do both X's fall on squares? The *manipulation* is the distance between the squares, with spacing of 2° or 7° of visual angle. The *score* is the time and errors for the widely spaced squares compared to the close spaced ones. If the attention window has difficulty encompassing a larger area, there will be retarded scores in the wide-spaced condition.



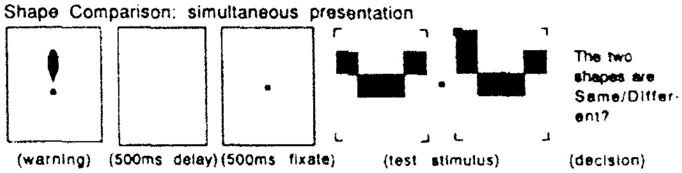
2. *Preprocessing*. The preprocessing subsystem is posited to extract the aspects of shape that do not vary over a wide range of different projections of the object. If this subsystem has a limited capacity, it may fail to encode enough of these characteristics to recognize the shape immediately. In this task, the subject merely indicates whether an X mark is on a figure. The figure is presented in an empty frame ("low load") or with randomly spaced line fragments placed over it ("high load"). The *manipulation* is load and the number of perceptual units in the figure (1, 2, or 3). If the preprocessing subsystem has a limited capacity, then we expect increased times and errors with additional perceptual units in the high-load condition, but not the low-load condition. Thus, the *score* is the increase in time or errors with perceptual units in the high-load condition over the corresponding increase in the low-load condition.



3. *Pattern activation.* The pattern activation subsystem is a visual memory. Two classes of deficits may occur here: subjects may fail to store information properly, or may fail to compare a new stimulus properly to stored representations. To test whether subjects can store patterns properly, they will study a pattern in brackets, will press a space bar when it is memorized, it will be removed for 3 s, and then an X mark will appear. The task is to decide whether the X would have fallen on part of the pattern if it were still present. The *manipulation* is the number of perceptual units (1, 2, 3) in the pattern, and the *score* is the increase in time or errors with units. If the subject has difficulty storing shapes, we expect increased difficulty with more complex shapes.



To assess the subject's ability to make shape comparisons, we present two figures, one to either side of a central point, and ask for a same/different judgment. Half the time the figures are identical, and half the time one is slightly different from the other. The *manipulation* is the number of perceptual units (1, 2, 3) in the pattern, and the *score* is the increase in time or errors with units.

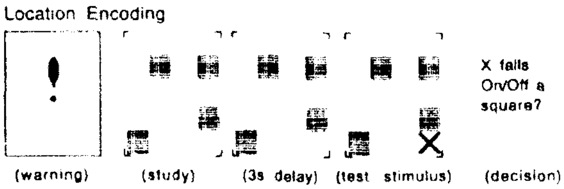


4. *Feature detection.* Color encoding will be examined as part of our first filter test, as will acuity (which is a prerequisite for detecting certain classes of textures).

Spatial-properties tasks

The following tasks are designed to diagnose specific deficits in the "spatial properties" system, which is implemented in part in the parietal lobes (see Ungerleider & Mishkin, 1982).

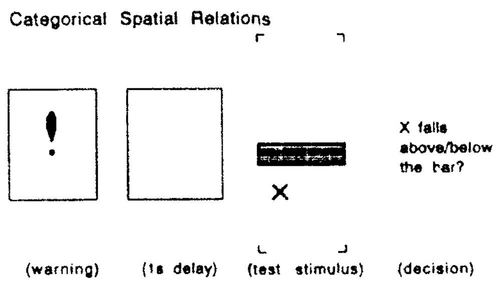
1. *Location encoding.* This task assesses whether location can be registered in the visual buffer. This task does not involve memory, but is otherwise analogous to the location short-term memory filter task. The subject is shown 4 gray squares, arranged like those in the filter task, and now the squares remain visible during the 3 s interval after the space bar is pressed, and then an X probe appears. The question is simply whether the X falls on or off a square. The *manipulation* is, as before, the number of squares (2 vs. 4), and the *score* is the increase in time or errors with increased squares. If the subject has difficulty representing the location, we expect increased times and errors when more locations must be processed.



2. *Spatiotopic mapping.* The task used to assess how well a subject can represent location relative to an object or other external frame of reference is exactly like the location short-term memory filter task, except that the test stimulus is not moved. If moving the test stimulus impairs performance in

the previous task, but not this one, we infer that the subject has difficulty representing location relative to the frame. Thus, the *manipulation* is the number of units, and the *score* is the increase in time or errors with units in the location filter task over the increase in this task.

3. *Categorical spatial relations encoding*. The subject sees a horizontal bar and an X, and decides whether the X is above or below the bar. The location of the bar moves randomly from trial to trial, so that the subject cannot simply look at a part of the screen to make the decision. The *manipulation* is the distance of the X from the bar; it is very close to the bar or is over 2 cm from it. Even among normal subjects, the decision is more difficult when the X is closer to the bar (this was also true in a "neural network" computer simulation model that was trained to do the task). The *score* is the increase in time and errors when the X was close to the bar compared to when it was farther. If a patient has a deficit in encoding this spatial relation, it should be exacerbated in the more difficult condition.



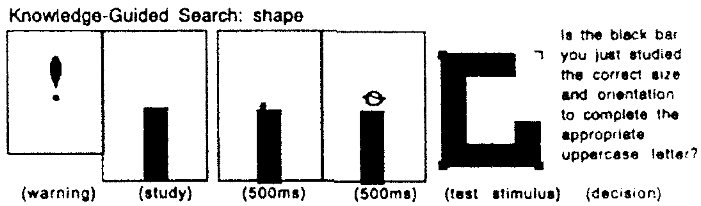
4. *Coordinate spatial relations encoding*. This task makes use of the same materials used in the categorical spatial relations encoding task, except now the subject is asked whether the X falls within .5 inches of the bar (and ignores whether the X is above or below the bar). The *manipulation* is the difficulty of the discrimination (whether the X is between .4 and .6 inches, which is difficult, or is between .1 and .3 or .7 and 1 inches, which is easy). The *score* is the increase in time and errors when the X was close to the criterion compared to when it was farther. If a patient has a deficit in encoding this spatial relation, it should be exacerbated in the more difficult condition.

Knowledge-guided search tasks

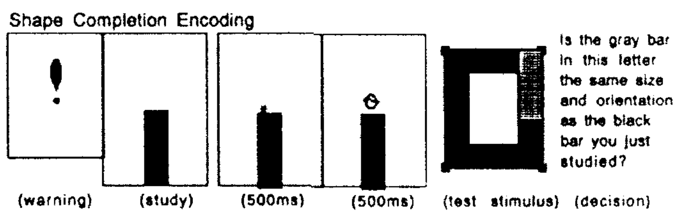
The following tasks are designed to diagnose specific deficits in the top-down search system.

1. *Knowledge-guided search: shape*. A failure on the knowledge-guided search filter task could be due to difficulties in encoding location, given that it uses a location-based judgment. This task assesses a subject's ability to access associative memory for information about a component of a shape and to search for that shape. The subject first is shown the block letters again. The test itself has the following structure: The subject is (after the usual trial warning exclamation point) shown a bar. After memorizing its size and orientation, he or she presses the space bar. An asterisk appears and then is replaced by a lower case letter. Shortly thereafter a fragment of a block letter is

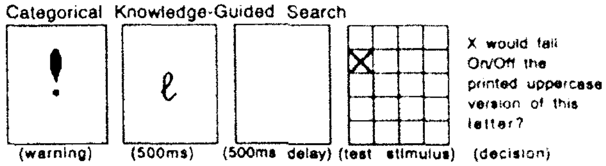
presented. The question is, can the bar studied at the outset be used to complete the shape fragment to form the block letter that is associated with the lower case cue? This task requires using the property lookup subsystems to access associative memory to locate a description of the shape, which is then used to direct attention to the location of the missing part. At this point, the representation of the bar must be used to determine whether it would complete the letter at that location. The *manipulation* is the number of segments in the block letter, and the *score* is the increase in time and errors with more complex block letters.



2. *Shape completion encoding.* Unlike the other tasks, the previous one does not have built-in controls; there are no simple tasks in the battery that allow us to check that the subject understands the instructions, can memorize the bar, and can perform the necessary shape comparison. This control task is identical to the previous task except that the missing segment is colored gray, and the subject must only determine whether it corresponds to the previously studied bar. The manipulation and scores are the same as in the previous task.

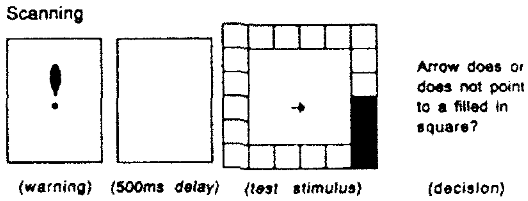


3. *Categorical knowledge-guided search.* Finally, if the subject is impaired at the filter task and the Knowledge-Guided Search: Shape task, this could reflect deficiencies in associative memory or in the subsystems that access and use stored information. The present task has been shown to require only the categorical subsystems (Kosslyn, 1988), and hence a patient with impaired coordinate spatial relations encoding or coordinate property lookup subsystems may be unimpaired on this task. The only difference between this task and the Knowledge-Guided Search filter task is that a 4 x 5 grid is present, allowing the subject to use internal descriptions of location easily (relative to rows and columns; see Kosslyn, 1988, for data supporting this claim). Both patients performed this task normally.

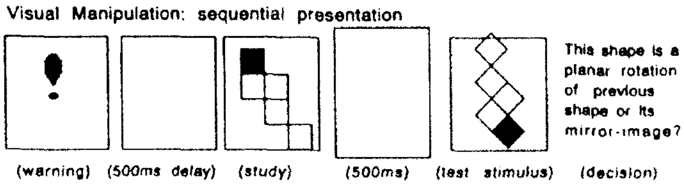


Visual manipulation tasks

1. *Scanning*. Just & Carpenter (1986) showed that subjects scan back and forth between the two stimuli in the kind of simultaneous-presentation mental rotation task used as our filter. (This scanning apparently plays a role in helping subjects keep the parts of the figure aligned during rotation.) It is possible that increased times or errors in this task could reflect impaired scanning. Thus, we assess the subject's ability to scan. A donut shaped grid is presented with 3 contiguous filled cells. An arrow is presented within the grid, and the subject is asked whether the arrow points at a filled cell. The *manipulation* is the distance between the arrow and the grid (3 distances are used), and the *score* is the increase in time or errors with increasing distances.



2. *Sequential rotation*. Another possible problem in rotation is accessing stored information; according to Kosslyn (1987), descriptions of how shapes are aligned are stored and used to guide the rotation process per se. Presenting stimuli sequentially forces the subject to use this kind of information, precluding the part-for-part comparison that is possible when two figures are present simultaneously. Thus, this task is like the visual manipulation filter task except that the stimuli are presented sequentially. Again, the *manipulation* is the angular disparity between the two figures, and the *score* is the increase in time and errors (i.e., slope of the best-fitting function) with increasing disparity.



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