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13. ABSTRACT *(Maximum 200 words)*

The research can be divided into work on (1) preattentive visual processing, and (2) work on visual memory and priming for previously perceived objects. Some of the main findings were as follows: (1) We showed that parallel, preattentive processing of motion and orientation depends on the elements sharing the same direction of contrast. However, some cues to occlusion appears also to be available preattentively, since they can control the correspondence matching in apparent motion. Preattentive grouping can guide attention in patients with neglect even though the elements are not consciously available. (2) Token representations of two novel objects can apparently be formed in a single trial. Attention then selects one of the two for response and inhibits the other. Its memory trace may nevertheless remain available to prime or interfere with subsequent perception of the same object. Similar priming and interference effects in visual search suggest that practice and automatisation may also depend on specific memory traces for each display, and that these are affected by the type of perceptual processing required by the search task.

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General Organisation

For the first eighteen months, the people employed by the grant were Amy Hayes, as technical assistant and coordinator for the first year, Ephram Cohen as part-time programmer, Julia Simovsky and Heather Rose (at different times) as clerical assistants, Todd Horowitz, Marcia Grabowecky, Brett De Schepper, Kathy O'Connell, Beena Khurana and Meg Wilson (at different times) as graduate student R.A.'s, and Irina Rivkin as an undergraduate lab assistant.

From September 5th, 1991 to the present, I have been on leave at the Russell Sage Foundation, New York. I am continuing to collaborate with my students in Berkeley, and to run experiments, communicating by e-mail with my research assistants there. I am also writing up several papers on research I had completed before leaving. I will return to Berkeley in July, 1992.

Research

We have worked on a number of different projects relating to visual perception and memory for features and objects. We are attempting to explore the processing that converts visual sensory data to representations of objects and events, and to define the role played by attention in this processing. We have also begun work on the effects of the initial perception of novel objects on their re-perception, either immediately, after a single presentation, or after multiple trials or long delays, using various priming tasks to explore the memory traces formed in different perceptual tasks.

1. Preattentive processing and apparent motion, with Todd Horowitz

Apparent motion is seen when two similar stimuli are presented in quick succession at some spatial displacements. We perceive one object moving from one location to another, when there is in fact no real motion involved.

Braddick (1980) and others (for instance Petersik, 1989) have argued that two separate systems are responsible for the perception of apparent motion. The short-range system, presumed to be based on low-level detectors early in the visual system, is responsible for the perception of real motion as well as apparent motion over short displacements. The perception of motion over larger displacements is assigned to a long-range system. This system is often conceived of as a higher level system, more "cognitive" or inferential in nature. However, there have been few proposals for mechanisms to explain the operation of the long-range system.

We have been exploring the idea that focused attention, in the sense of Feature

Integration Theory (Treisman & Gelade, 1980; Treisman & Sato, 1991), is the mechanism responsible for the perception of long-range motion. Recent studies using the visual search paradigm to investigate apparent motion (Ivry & Cohen, 1990; Dick, Ullman, & Sagi, 1987) suggest that differences in short-range motion are detected in parallel, as if they were sensed by specialized feature detectors, whereas attention is necessary to create the impression of long-range motion, perhaps because the two successive presentations must be integrated into a unitary percept in the same way as feature integration theory suggests for the different parts or properties of a single object. We replicated these results, using search for vertically oscillating targets among horizontally oscillating distractors. Time to find targets in the short-range condition was independent of the number of distractors, while RT increased linearly with set size in the long-range condition.

The feature integration account suggests a further prediction when other criteria for contrasting the two forms of motion are applied. If the short-range system can be described as a parallel preattentive system, in contrast with an attentive long-range system, then other factors which rule out the short- range system should also force the use of focused attention in the perception of apparent motion. Anstis & Mather (1975) suggest that one such factor may be reversal of contrast within a stimulus in apparent motion. This would agree with other evidence suggesting that information carried by bicontrast stimuli cannot be extracted preattentively (O'Connell & Treisman, 1991, see section 2 of this report). To test the generality of this conclusion, we looked at search for targets defined by direction of motion, using bicontrast stimuli. Subjects searched for vertically oscillating targets in four conditions created by crossing bicontrast vs. unicontrast stimuli and long vs. short displacements. The unicontrast conditions replicated previous results. Short-range targets were detected in parallel, while long-range performance suggested serial search. In the long-range conditions, bicontrast and unicontrast search slopes were nearly identical for both positive and negative responses, corroborating the indifference to contrast reversal reported for the long-range system by (Pantle & Picciano, 1976). However, short-range search was seriously disrupted by contrast reversal, forcing the use of focused attention.

This contrast type X range interaction argues against a unitary explanation of apparent motion perception. However, without examining search rates over a continuum of intermediate positions, it is difficult to claim a sharp processing dichotomy. The hypothesis therefore calls for converging evidence. If attentive motion detection depends on a different mechanism from the short-range motion detectors, their independence might be demonstrated by selective adaptation experiments. Adapting to short-range motion should leave long-range and bicontrast motion detection unaffected, while reducing the efficiency of search for short-range motion displays. On the other hand, if the short- range bicontrast stimuli are coded by short-range motion detectors, but less efficiently than equivalent unicontrast stimuli, they should show an impairment in search after prior adaptation.

2. Coding of orientation, with Kathy O'Connell

With Kathy O'Connell, I continued the research on preattentive orientation coding that we began under the last grant. Our main findings can be summarized as follows.

Orientation can be carried by a number of different "media," including lines, edges, pairs of dots, and subjective contours. We investigated whether the coding of orientation is shared by different media, using a visual search task for targets defined by conjunctions of a particular orientation and a particular medium. When half the distractors share the target orientation in a different medium they should interfere with target detection if and only if the orientation code is shared by the two media. The results showed substantial effects of display size in search for conjunctions with lines and dot pairs of shared contrast, and with lines and edges, although both orientation and medium could be detected in parallel for targets defined by any one of these features alone. The orientation of bicontrast dot pairs (one black dot and one white dot on an intermediate gray background) could not be detected in parallel. The stimuli that show parallel coding in feature search and interferencein conjunction search seem to correspond with those that drive orientation-selective cells in the early visual areas.

Under the new grant we carried out several additional experiments testing whether shared color, or an enclosing line or spatial contiguity, can overcome the difficulty in preattentive coding of orientation for the virtual line connecting a pair of dots of opposite contrast. None of these grouping aids allowed parallel coding of these bicontrast dot pairs. We conclude that the preattentive coding of orientation is possible only for dots of shared contrast.

We are curently revising a paper reporting this research prior to resubmitting it.

Kathy O'Connell has also been exploring preattentive orientation coding using White's Illusion to determine whether orientation is coded before or after the brightness contrast effects that cause the illusion. On a black and white square wave grating, a gray square on a white stripe will appear darker than a gray square of equal luminance on a black stripe. This is true even when the squares are the same width as the bars, so that both have two sides bordering white and two sides bordering black, thus eliminating the simple simultaneous brightness explanation. This orientation-dependent lightness contrast effect is called White's Illusion. To determine whether White's Illusion is pre-attentive, she employed a visual search paradigm. The target was a gray square on a white stripe, and the distractor items were equally bright squares on black stripes. The target square appeared darker than the others, and popped out from the display. Search times were independent of the number of items in the display. It seems that lightness contrast may operate at a pre-attentive level. Control experiments are planned to ensure that the results are truly testing the ability to use lightness contrast pre-attentively, and do not simply reflect an alternative strategy, such as looking for the sole item on a white stripe.

3. Preattentive processing of scene-based properties: Research by Beena Khurana

Recently Enns and Rensink (1990) have shown that early vision has access to scene-based properties such as three-dimensionality and direction of lighting. In a visual search paradigm with line-drawn stimuli, subjects could use differences in apparent three-dimensional orientation and lighting to distinguish the target cube from the distractor cubes. Control patterns of similar complexity that did not give an impression of depth required serial search.

Given that certain scene-based properties can be detected in parallel, one may ask whether the motion system can also use these properties in solving the correspondence problem. Observers viewed a motion sequence that consisted of four frames, each consisting of two pairs of patterns, interleaved in a circular array. In one sequence, the matching patterns adjacent to each other in successive arrays followed a clockwise path, and in the other sequence it followed an anti-clockwise path. If the two patterns were distinguished by the correspondence process, then motion should be seen in the direction dictated by the sequence of matching frames on that particular trial. If, on the other hand, the correspondence process does not distinguish between the objects, then perceived direction of motion should as often agree as disagree with the presented frame sequences. When objects that are perceived as three-dimensional cubes are presented with two-dimensional control patterns in the above described motion sequence, observers overwhelmingly report the perceived direction of motion in agreement with the frame sequences. In other words, the correspondence process distinguishes between three-dimensional cubes and their two-dimensional counterparts. Correspondence strength based on other scene-based properties such as direction of lighting is under investigation.

4. Preattentive guidance of attention in patients with neglect, with Marcia Grabowecky.

Preattentive processes, such as perceptual grouping, are thought to be important in the initial guidance of visual attention and may also operate in unilateral neglect by contributing to the definition of a task-appropriate reference frame. We explored this possibility with a visual search task in which patients with unilateral visual neglect (5 with right-, 2 with left-hemisphere damage) searched a diamond-shaped matrix for a conjunction target which shared one feature with each of two distractor elements. Additional grouping stimuli appeared as flanks either on the left, right, or both sides of the central matrix, and significantly changed performance in the search task. As expected, when flanks appeared only on the ipsilesional side a decrement in search performance was observed, but the further addition of contralesional flanks actually reduced the decrement and returned performance to near baseline levels. These data suggest that flanking stimuli on the neglected contralesional side of visual space can influence the reference frame by grouping with task-relevant stimuli, and that this preattentive influence can be preserved in patients with unilateral visual neglect.

Marcia Grabowecky is continuing this work with patients. She is exploring the influence of similarity at the feature level between flanking stimuli and the search displays, on the apparent shift in reference frame found in the experiment reported above. The results may reflect both a form of grouping by similarity and a grouping at the level of figure-ground segregation, determined by the center of mass of blobs or global objects in a display. Marcia is now trying to tease apart these factors in patients and also collecting evidence for their operation in normals. Her idea is that the center of mass of a display may be influenced by the density and distribution of the individual elements it contains. Earlier research has shown that saccades are directed towards the center of mass of a group of elements arrayed in the periphery: thus, saccades to a clearly discriminable target overshoot if additional elements appear beyond them and undershoot if the extra elements are between the target and the fixation point (Coren & Hoenig, 1972). There may be advantages in having a mechanism that directs the eyes to the center of potential objects, a convenient position from which to produce subsequent, more precise, exploratory movements. This same mechanism is likely to move attention before the saccadic eye movement occurs, (Posner, 1980; Shepherd, Findlay, & Hockey, 1986), increasing the advantage of the subsequent fixation.

If this conjecture is correct, we might predict that manipulations which influence saccadic eye movements will also influence the movement of attention. An experiment in normals is in progress to show that manipulations which affect the accuracy of saccades to a target will also influence target detection if attention is necessary to detect those targets. This experiment will use short display durations to prevent eye movements to the stimulus array, and will manipulate the center of mass of stimulus arrays.

5. Relations between feature identification and localization

We have previously shown that in conditions of divided attention subjects can identify feature-defined targets significantly better than chance even when they mislocalize them. Feature information seems to be partly independent of location information. However, most of the location errors when the feature is correct were to adjacent locations. One possibility in that features have coarsely coded locations attached as an integral part of their representation (Cohen & Ivry, 1989). Another possibility is that attention can be coarsely focused very rapidly on one half of the display or the other, giving the rough area in which a feature is located. In order to test these alternatives, we manipulated the focus of attention. In one condition, subject spread their attention across the display to identify two digits, one on each side of the colored distractor and target bars. In the other conditions the digits appeared together, adjacent and more peripheral than one of the colored bars, following a brief peripheral cue to their location. We compared the interdependence of feature identity and location for items in the three locations adjacent to the digits and in the five more distant locations. We found little difference between the near and the far locations, or between either of these and the previous divided attention condition. However, we may not have succeeded well in controlling attention, since our subjects made a large number of errors in reporting the digits. We will try a more salient cue and test the digits on a larger proportion of trials.

6. Object perception and attention in negative priming experiments, with Brett De Schepper.

The research in this section explored the process of seeing without identification. We hoped to bring out a distinction between object types - the stored descriptions or models of previously seen objects to which we match present stimuli, - and object tokens - the temporary representations which mediate the perception of a particular stimulus, whether known or unknown, in its current color, illumination, distance, viewing angle and orientation (Kahneman & Treisman, 1984).

The task we used to explore the formation of object tokens was the negative priming paradigm, first developed by Greenwald (1972) and later elaborated by Neill (1977) and by Tipper and his colleagues (Tipper, 1985; Tipper & Driver, 1988). Negative priming is shown when a stimulus which was irrelevant on one trial becomes the relevant stimulus on the next. The switch often results in a slower response than is made to a control stimulus that was not previously unattended, as if the irrelevant item had been inhibited to prevent it from competing for response. The inhibition then lingered into the next trial and had to be lifted before the new response could be made.

In a series of experiments, we used the negative priming effect to investigate the nature of the representations to which the inhibition may be attached. In particular, we tested whether a novel object with no pre-existing representation in memory would show negative priming, in the same way as familiar letters or pictures. This result would suggest that episodic tokens are formed on a trial by trial basis to represent each current, unfamiliar object, even when it is not the relevant item controlling the response.

The first experiment tested for negative priming using novel forms (Figure 1a) such as those used by Rock & Gutman (1981). We used a same/different matching paradigm in which subjects decided as quickly as possible whether the green shape in an overlapped pair matched a white shape presented separately to the right of the pair. We found a significant negative priming effect when the unattended red shape on one trial became the attended green shape on the next trial. This first result shows that negative priming is not restricted to meaningful or nameable stimuli. Inhibition can be attached to meaningless visual representations. It is interesting to note that Rock and Gutman found no explicit memory whatever for the unattended stimuli in their experiment with similar overlapped pairs of meaningless shapes. They concluded that attention is necessary to identify shapes and to lay down retrievable traces in memory. It seems that the negative priming task may lay down traces in a separate memory system that is not accessible to voluntary explicit retrieval (Musen & Treisman, 1990; Schacter, Cooper & Delaney, 1990).

A further experiment showed that negative priming occurred on the very first presentation of a novel figure, and also that inhibition may accrue across blocks, resulting in increasingly slowed response times with each additional presentation as an ignored figure.

Another experiment compared the effects of attention on the attended shape and on the unattended shape, to see whether attention produces activation for the relevant stimulus as well as inhibition for the irrelevant one. This time we used simple repetition priming instead of switching the role of the previously unattended shape. The question was whether subjects would be faster on the attended shape if it was also attended on the previous trial and whether they would also be faster if the unattended shape was also unattended on the previous trial. The results showed both effects: 25 ms benefit when the attended shape was repeated, and 15 ms when the unattended one was repeated. Although there was a hint that the benefit was larger when the attended shape was repeated, the difference was not significant. Attention in this paradigm seems to produce both activation relative to a baseline for the relevant shape and inhibition for the irrelevant one.

In the experiments described so far the two shapes competed while remaining independent entities, with potentially equal status perceptually, except that one was selected to control the response. A different kind of competition may arise when one of two shapes has the status of figure and the other is seen only as the background, as in Figure 1b. The two shapes then share a common contour which is normally allocated only to one of the two. The background shape is typically not consciously represented in perceptual experience, not just because it is unattended but because its contour is allocated to the figure and given a different interpretation (e.g. certain curves are seen as convexities rather than concavities). In this case, we surmised that inhibition might be unnecessary; the shape of the background would simply not be represented; it would not exist as such for the perceptual system.

In order to test this possibility, we used two priming conditions: In one the shapes shared a common contour and in the other they were separated, giving them equal status perceptually. Subjects were asked to match the shape whose <u>color</u> (white or black) matched that of a standard shape presented below the pair. The two shapes on the probe trials were always separated and always different, so they never shared the shape of their central contours, whereas the two shapes on the priming trials always did, whether they were spatially separated or together. The relevant shape on negative priming trials was the irrelevant shape from the preceding priming trial, (seen either as ground or spatially separated), while on control trials it was a new shape. We found negative priming <u>only</u> in the figure-ground condition. When the shapes were separated in the prime pair, there was actually some facilitation, averaging 13ms,(not significant). Perhaps because the two shapes were separated, (rather than overlapped, as in the earlier experiments), there was less competition and therefore less need for inhibition of the unwanted shape.

The fact that the shape of the background in the prime trial interfered with responses when it became the figure on the probe trial suggests that inhibition is attached to the representation formed at a level earlier than the suppression which ensures awareness only of the shape of the figure. These conclusions so far are only tentative: It could be that subjects had time to attend to both figure and ground on some proportion of trials or that they selected the wrong shape initially and that the negative priming occurred only on those trials. We plan to run versions of the experiment in which the relevant color is precued and in which the figure is moving against a stationary background, in order to decrease the probability that the ground would also receive attention. If the results are confirmed in these versions of the experiment, they will suggest that the dividing contour is initially attached both to a representation of the shape that is subsequently seen as the figure and also to a representation of the shape that is not seen because it has been interpreted as the ground. Both must then exist at some preperceptual level, just as psycholinguists have concluded that both interpretations of ambiguous words are initially activated before a choice is made to determine the single conscious interpretation (e.g. Swinney, 1979).

7. Integration of features within or across dimensions: research by Beena Khurana and Marcia Grabowecky

A set of experiments on feature integration of within-dimension conjunctions (color-color conjunctions) has been completed. They indicate that the attentional cost of processing within-dimension conjunctions lies not in an inherent bottleneck on the transmission of information from feature modules, (as suggested by Wolfe et al. 1990) but rather in the spatial separation of features. These experiments also reveal that attention may operate using feature inhibition that is limited to the space occupied by the individual features. This inhibition does not automatically spread to other parts of the visual object that are occupied by the individual features. In other words, the inhibitory processes in search may act at the spatial resolution of features and not whole objects.

8. Occlusion inferences and feature integration: research by Beena Khurana

Beena Khurana has found that occlusion structures are available pre-attentively and can modify the subsequent synthesis of other feeatures such as the color of contours. Contours which typically create a strong occlusion structure were employed. The colors of the contours were such that they were consistent either with the occlusion structure or with a mosaic interpretation. The contours of the occlusion-inconsistent patterns were more likely to be seen in the color of the occlusion-consistent pattern under conditions of attentional overload. Experiments with two-dimensional control stimuli showed that the constraint imposed by the occlusion structure operates not at the level of local line continuity but rather at the level of global figural occlusion.

The stimuli used in the above experiments can be analyzed in terms of color and luminance information. The occlusion-consistent and the occlusion-inconsistent stimuli are indistinguishable through luminance in that they are both interpreted as occlusion structures. Only the color information differs. The findings suggest that the perceived colors are affected by the three-dimensional structure signalled through luminance information. Two approaches are being used to test this hypothesis. If the luminance channels determine the three-dimensional structure that in turn constrains the colors, the same spatial patterns defined by equiluminant contours should not give rise to the color illusions. Secondly, by using bi-contrast stimuli, with some contours in black and some in white on a grey background, we may be able to determine at what level the luminance patterns are mapped onto three-dimensional interpretations. These experiments address the current debate in Neuroscience about the distinction between the magnocellular pathway (luminance) and the parvo-cellular pathway (color), and they explore the perceptual implications of the neural independence of on and off pathways in the visual system.

8. Levels of attentional inhibition in negative priming: research by Brett De Schepper, Meg Wilson, Kathy O'Connell, and Beena Khurana.

Attention may affect not only response selection but also other levels of perceptual processing. Several of my graduate students have devised a search version of the negative priming paradigm to explore what aspects of a perceptual display can be inhibited; specifically, whether the process of selection may leave residual inhibition not only on the responses, but also on the perceptual features used for selection. In order to vary the selection cues across trials, they used an "odd-man-out" task with multi-item displays. Their subjects selectively attended and responded to the "odd-man-out" in a display of six items and ignored the other items. Either the selection features or the response features of the ignored items could then be repeated in the attended item of the subsequent trial.

In one experiment, they directly tested the hypothesis that negative priming may occur for features that are used for selection only and are independent of responses. Subjects selected the "odd-man-out" on the basis of one feature and then responded to it by naming a different feature. Some subjects selected the "odd-color-out" and named the letter in the odd color; others selected the "odd-letter-out" and named the color of the odd letter. They showed significant negative priming for both colors and letters, although the effect was larger for letters than for colors. Since the attributes that were primed in this experiment were used only for selection, this result suggests that negative priming may not be simply due to "selection for action" from among competing responses. The act of selection seems to leave residual inhibition on perceptual features used only for selection.

Another question that the students attempted to answer in this study was whether perceptual features that are completely irrelevant to the task are also inhibited. To examine this possibilty, they ran a series of experiments in which a third attribute was introduced to be used for selection. The other two dimensions (colors and letters) could then be used to test for priming of the response and priming of the irrelevant dimension. The selection attribute was letter size in one experiment, target flicker in another, target motion in another, and a target marker in another. The results of these experiments are inconclusive so far; the irrelevant attributes show negative priming in some cases but not others.

9. Attention and object tokens in search automatization, with Amy Hayes

We continued the research begun on my previous grant, exploring the effects of initial perception on later re-perception in search tasks for feature and conjunction targets.

When extended practice in search is given, substantial changes occur. Complex shapes may eventually appear to be detected automatically (Vieira & Treisman, 1988). On the other hand there is very little transfer from this learning to other tasks using the same overlearned shapes. We suggested that the automatization we observed might depend on specific object tokens, traces left by each experience of a particular target display, as in Logan's exemplar model of skill acquisition (Logan, 1988). The research in this section explored some effects of the type of perceptual processing on the memory traces that are evoked, both in long term practice effects and in short term repetition priming.

When we look at a scene, we have the option of dividing attention to process it globally, or of focusing attention on one object at a time. We suggest that when attention is divided, all the features within the attention window are processed in parallel, but only their global layout is available. The presence of a single unique feature will "pop out" of a display, but it may be poorly localized and its particular conjunction of other features will not be available until attention zooms in to that element alone.

These distinctions between perceptual modes of processing have implications for the form that re-perception will take. To manipulate attention, Amy Hayes and I used two different visual search tasks: search for targets defined by a single feature and search for a conjunction of features. In conjunction search, attention is directed to an object and all its features are automatically integrated with their location and with each other. On the other hand, in feature search no individuated object tokens are needed. If skill acquisition depends on reactivating earlier object tokens, we therefore expect more specificity in conjunction than in feature search.

The experiments all shared the following design. The task was visual search for any one of three or four targets among six or eight distractors (non-targets) presented in a circular array. On each trial there was either one target present or none and subjects pressed are not conjoined to fit the target definition.

The results support the idea that the effects of practice in the automatization of search are mediated by an accumulation of specific memory traces. The task required during perception has a large effect on what is learned. When attention must be focused to set up separate individuated object tokens specifying how the features are conjoined, the speeding of responses depends on the degree of match to the most frequently experienced objects. When parallel processing with divided attention is sufficient, the contingencies have little or no effect on automatization. Subjects presumably form a global object token for the display as a whole, representing the presence of the particular target feature without individuating the element that carries it.

10. Short term repetition priming in search

Another implication of the idea that automatization reflects the accumulation of specific object tokens is that a new memory trace for the current appearance of the target is formed on every trial. If this is the case, it should be possible to probe for its presence immediately after each particular experience by looking for content-specific priming of each trial on its immediate successor. We expect to find similar effects of experimental variations on this short term priming measure and on long term learning in skill acquisition.

To test this idea, we used the same search data, but looked at each trial as a function of what was repeated from the preceding trial. It could be the same target in a changed location, the same location with a changed target, or the same target in the same location, or it could be a completely different target and location. We compared the latencies on each type of repetition trial to those on control trials, which were identical except that they followed a trial on which no target was presented, so no repetition benefit could occur. This allowed us directly to compare the specificity of the long term learning with that of the short term repetition priming in the same experiments.

In the first experiment I described (with location-biased pink and green letters in conjunction search and colored bars in feature search), we found a significant short term priming benefit for exact repetitions of both target and location, averaging 15% for conjunctions and 10% for feature targets. When the same target was repeated in a different location, the benefit was halved and was no longer significant for the conjunction targets. When the same location was repeated but the target changed, the benefit disappeared altogether and in fact became a slight but non-significant cost for the conjunction targets. Thus in this experiment, the short term, trial-to-trial priming seems to be fairly specific, particularly for conjunction search: Both the identity and the location must be repeated to ensure that the preceding target token is re-perceived.

In the experiments in which we introduced consistencies with irrelevant features as well as locations, we again found evidence of specificity in the short term priming for conjunction search, and this time none at all for feature search. There was a significant benefit in conjunction search only when the target was repeated with the same irrelevant feature or in the same location as on the previous trial. In feature search, on the other hand, we got the same benefit from repeating the feature targets whether or not their irrelevant features were changed. Thus the task required during perception seems to determine whether separate object tokens are established. Trial-to-trial priming occurs both for a target feature in feature search and for a target conjunction in conjunction search. However it seems to depend on individual object tokens in conjunction but not in feature search.

In the search tasks described above, the results were very similar for short term priming and for long term learning, as they should be if the same specific object traces are involved. However, there were also some intriguing differences, suggesting possible changes in the mode of retrieval over time. For conjunction targets, there seemed to be a change between the short and the long term measures in what produces a cost. A mismatch on location when the location-biased target appeared in an unexpected location was very costly in the long term measure, whereas changing the location produced no cost in trial-to-trial priming. On the other hand, in short term priming, there was a slight (though not significant) cost of changing the target when the location was repeated.

This pattern of costs and benefits suggests an asymmetry between the retrieval cue and the content of what is retrieved. Early on, the location of the object is a powerful cue for retrieval. If the currently attended location matches that of the previous target, its content is retrieved and produces a benefit when the targets match and a small cost if they do not. Once a token has been retrieved, however, the location information stored with it may also become salient and substantially delay the response if there is a mismatch with the location of the presently attended object, or speed it up if both target and location match. Thus, in long term learning, subjects directly retrieve information about targets, including where they are likely to appear; they are less likely directly to retrieve information about locations, specifying which objects each location is most likely to contain.

11. Priming in feature and conjunction search: research by Todd Horowitz

Todd Horowitz is also, independently, investigating trial-to-trial priming in feature and conjunction search. He is interested in the role that location plays in feature integration and identification. In feature integration theories of vision (Treisman & Sato, 1991; Wolfe, Cave & Franzel, 1991), conjunction searches require attention to be directed to various locations in the visual field in order to identify combinations of features at those locations. Todd's hypothesis is that this activity leaves some trace in the system, "priming" feature integration at that location. This would not be true in feature searches, where subjects do not have to attend to locations to detect a target.

He has conducted pilot experiments in which subjects look for either feature or conjunction targets. Trials are paired (though this is not evident to the subjects) such that half of the time the target on the second trial appears in the same place as did the target on the first trial. In agreement with the hypothesis, reaction times in the conjunction condition are significantly facilitated when the target location is repeated compared to when it appears at a different location. In contrast, the priming manipulation has no effect in the feature condition.

Several papers describing these projects have been written, and are either in press, submitted, or under revision. They are listed below. For the remaining period of grant support, we will continue to work on these projects and develop others that arise from them. We are grateful to AFOSR and ONR for the financial support which makes the research possible.

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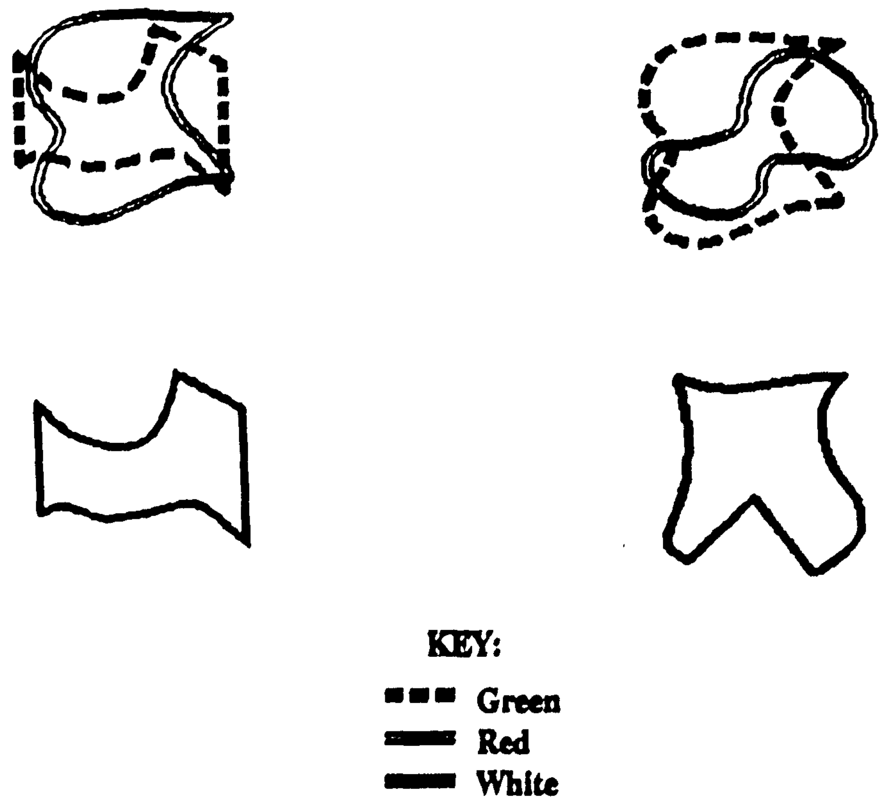
Example of stimuli used in experimental trials. Experimental trials consist of prime and probe displays in which the irrelevant figure in the prime is repeated as the relevant figure in the probe. In this example, subjects would compare the white figure to the green figure and respond "same" to the prime and "different" to the probe.

Prime: Probe:

A



Example of prime and probe pair in the figure/ground negative priming experiment. In this example, subjects would compare the black figures in the prime (and respond "same shape") and compare the white figures in the probe (and respond "different shapes").

B

Prime Probe