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The Representation of Location in Visual Images

by

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Abstract

Three experiments explored the encoding of location information in visual image representations. All of these experiments used a mental rotation task in which subjects decided whether stimuli were mirror-reversed, and the location of the test stimulus was always irrelevant to the correct response. Experiment 1 demonstrated that subjects were able to use visual image representations effectively without knowing where the stimulus would appear, raising the possibility that image representations might be coded independently of location. In Experiment 2, however, distance between the stimulus location and the image location was varied systematically, and response time increased with distance. Therefore image representations appear to be location-specific. The increase in response time with distance was small, however, and thus represented location must be adjusted quickly. In Experiment 3, a saccade was introduced between the image cue and the test stimulus, in order to test whether subjects responded more quickly when the test stimulus appeared at the same retinotopic location or same spatiotopic location as the cue. The results suggest that location is coded retinotopically in image representations. This finding has implications not only for visual imagery but also for visual processing in general, because it suggests that there is no spatiotopic transform in the early stages of visual processing.

Thesis Supervisor: Steven Pinker

Title: Associate Professor of Cognitive Science

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The Representation of Location in Visual Images

No explanation of visual information processing will be complete without an account of visual imagery: The ability to recall visual and spatial information from memory and to mentally recombine, transform, compare, and evaluate this information. Subjects can perform a number of complex visual processing tasks in the absence of the relevant visual stimuli, and over a period of years an enormous number of experiments have been designed to elucidate the nature of the mental representations used in these tasks. (For reviews, see Kosslyn, 1980; Shepard & Cooper, 1982; Pinker, 1984; Finke & Shepard, 1986. For discussions of the sharp disagreements that persist over the basic properties of these representations, see Kosslyn, 1981; Pylyshyn, 1981; Pylyshyn, 1984).

A number of visual image experiments have demonstrated that certain spatial properties play an important role in the organization of image representations. It is because of their spatial organization that these representations are called "images," and the nature of their organization has been an important question in the study of mental representations. While other studies have investigated the importance of orientation and size in image representations, the experiments described here will be concerned with another spatial property, namely location, that has not yet been thoroughly explored. There are good theoretical reasons for expecting that image representations might be encoded independently of location, and other empirical reasons for concluding that location information is included in the representation. If we find that image representations are location-specific, then we can test whether location is encoded in a retinal reference frame or in some other coordinate system. If, instead, image representations are location-independent, then we can ask why this particular spatial property is factored out of these representations and others are not.

Our experiments to explore location representation draw heavily on earlier experiments exploring the representation of orientation and size. These experiments were designed to measure how the processing of a stimulus changes when its orientation or size changes. The logic behind these experiments is that if the time to perform a particular shape discrimination task depends on the orientation or size of a stimulus, then the shape representations used in this discrimination task must vary in some important way when the orientation or size of the stimulus varies. In other words, the representation of shape must in some way be intertwined with the representation of orientation or size, so that shape cannot be represented independently of these spatial properties (Pinker, 1984).

Well-known examples of experiments measuring the importance of a spatial property come from studies of mental rotation by Shepard and his colleagues (Shepard & Metzler, 1981; Cooper & Shepard, 1983). In these experiments, subjects were asked to determine whether a visual stimulus matched another stimulus that was either presented simultaneously or remembered by the subject. On different trials, the stimuli appeared at different orientations, and over the course of the experiment the difference between the orientations of the two shapes to be compared was systematically varied. The time necessary for subjects to compare the shapes increased as the difference in their orientations increased. Thus, even though orientation was irrelevant to the shape matching task, it exerted a strong effect on the response time. The response time depends on the absolute difference between the two orientations. In general, the response time for a stimulus that has been rotated in one direction will be about the same as the response time for a stimulus that has been rotated an equal amount in the other direction.

Other experiments have used similar methods to demonstrate that the time to compare two shapes can vary with the difference between their sizes as well as the difference between their orientations (Bundesen and Larsen, 1975; Bundesen, Larsen, and Farrell, 1981; Cave & Kosslyn, 1989; Kubovy and Podgorny, 1981; Larsen, 1985; Larsen and Bundesen, 1978; Sekuler and Nash, 1972). These size and orientation experiments do not always produce a strong relationship between the spatial properties and response time; response time varies with size or orientation difference only when certain shape discrimination tasks are used. Apparently the image representations, in which shape is encoded integrally with orientation or size, are only used for some shape discrimination tasks. Examining the nature of these tasks can help determine the sort of processing for which these representations are best suited.

For instance, the stimuli in Cooper & Shepard's experiment were familiar letters or numerals, and subjects had to judge whether or not they had been mirror-reversed. Any shape and its mirror-reversal will share the same set of basic visual features, and thus they cannot be discriminated simply on the presence or absence of one of those features. The mirror-reversal judgment forces subjects to detect subtle differences in the spatial arrangement of a shape's components. Not all of the experiments in which the response time varies with spatial properties require mirror-reversal judgments, but they all do require subjects to detect subtle differences between shapes that share the same general features.

Not only are the shape discriminations used in these tasks very subtle, but they are also discriminations that the subjects have not practiced. In Shepard & Metzler's experiment, subjects compared two different drawings of three-dimensional shapes that were presented simultaneously. The subjects were not familiar with the shapes before the experiment, so they had no experience with the required discriminations. Cooper & Shepard used a different method in a later experiment. They presented only a single letter or digit on each trial. The orientation of these stimuli varied, and subjects presumably compared them against memory representations of those characters at their standard orientations. Even though subjects are very familiar with these shapes, they do not normally encounter them at nonstandard orientations, and they almost certainly never need to distinguish these misoriented shapes from their mirror reversals. Therefore, they do not have stored in memory the information necessary to readily identify these shapes at nonstandard orientations. Instead, subjects appear to perform the shape comparison by first deriving the necessary information from the information they have available. Either the memory information can be transformed to match the stimulus information, or the stimulus information can be transformed to match the memory information.

From these studies it seems that subjects use image representations when they must find subtle shape or configurational differences that they do not normally need to detect. Obviously, the representations used in these tasks must be orientation-specific: Because of the wide response time differences with different orientations, the same shape at different orientations must be represented differently. Also, because the response time increases steadily with orientation differences, the represented orientation must be adjusted gradually, either continuously or in small discrete steps.

Cooper and Shepard provided additional evidence as to the nature of image representations in other conditions of their experiment. Although the regular condition showed that extra time was necessary to process stimuli at nonstandard orientations, subjects could save most of this extra time if they knew the shape and the orientation of the upcoming stimulus before it appeared. They were able to use shape and orientation information together to prepare for the stimulus, and then respond quickly once it appeared. Apparently subjects prepared for an stimulus by creating an image representation of the stimulus at the cued location, because they could not prepare if they knew only the shape or only the orientation; in either of these cases, response times once again rose sharply with orientation difference. Response time also increased sharply with orientation difference if the stimulus appeared too soon after the cue giving the shape and orientation. Subjects required a certain amount of time to prepare for the stimulus. Most importantly, the time necessary to prepare generally increased with the orientation difference. In other words, the variation in the time necessary to prepare was similar to the variation in response time when the cue was not present.

Because a similar pattern appears in the response times without the cue and in the preparation times with the cue, a similar sort of transformation might be occurring in both cases. Without the cue, subjects might adjust the represented orientation of the stimulus until it matches the standard orientation, and then compare it to the memory representation. When subjects know shape and orientation in advance, they might adjust the representation of the shape in memory so that it matches the upcoming stimulus. Once the stimulus appears, they can quickly compare shapes without taking time for orientation adjustment. The fact that subjects cannot prepare effectively when they know only the shape or only the orientation suggests that orientation is represented integrally with shape. For the representations used in the mirror-reversal task, it is apparently not possible to represent a particular orientation without representing a specific shape at that orientation.

Knowing something about the nature of the image representations used in this task allows us to investigate the role they play in visual information processing. Let us first consider the broad course of visual processing, in order to see where these representations might fit. The input provided by the retina at the beginning of visual processing is organized spatially: Shape information is intertwined with information about spatial properties such as location, size, and orientation. The visual system must identify objects by comparing patterns within the input with patterns stored in memory. This categorization task is complicated by variations in spatial properties such as location, orientation, and size that are irrelevant to an object's identity. The final product of visual processing must be an abstract representation that can be used in higher-level reasoning and problem solving, and this abstract representation must include information about both the identity of the represented objects and their spatial properties. However, because the spatial properties will often be irrelevant in these higher-level processing tasks, information about these properties is probably factored apart and represented separately from identity information at this level.

If this characterization of visual processing is correct, and if the mirror-reversal task relies on a representation in which shape is represented integrally with orientation, then the comparisons between shapes in the mirror-reversal task must be done within the spatially-organized representation at the precategorical level, before objects have been identified and coded abstractly, and before spatial properties have been factored out. Within the spatially-organized representation, it is impossible to represent a shape without representing it at a particular orientation, just as it is impossible to draw a picture of a shape without drawing it a a particular orientation. Likewise, at this level it is impossible to represent an orientation abstractly without having an associated shape. Thus subjects are unable to prepare an adequate representation when they know only the shape or the orientation beforehand.

Of course, this characterization of visual processing is too simple in many respects. There are undoubtedly a number of stages between the spatially-organized representation from the retina and the abstract representation used by nonvisual cognitive systems. Therefore we can ask more detailed questions about the level of representations used in the mirror-reversal and other imagery tasks. For instance, if there are many different processing levels, then variations in location might be controlled at an earlier level of processing than variations in orientation. Thus there could be some level of representation that is location-independent but orientation-specific. This type of representation might be useful, because the location at which an object appears has little impact on recognition (barring differences in surroundings and acuity). The same is not true for orientation, however, because some objects can be very difficult to recognize when they are upside-down (Rock, 1983). Luckily, this is rarely a problem in everyday visual processing. As we move or as objects in the environment move, the locations of the objects relative to our location can vary over a wide range, and we have to be able to recognize them no matter where they appear. However, as we move we generally maintain a constant orientation relative to the environment, and most of the other moving objects we encounter do the same. Therefore we generally view objects at a standard orientation, and rarely find it necessary to recognize them at other orientations.

Because visual objects are likely to occur at almost any location, the visual system may factor out location differences early in processing, either by normalizing all representations to a standard representation of location, or by transforming the input in a way that removes location information entirely. However, the visual system will often not need to adjust an object's orientation before identifying it. Thus the system that corrects for orientation differences may may not act until a later stage of processing, and it probably does not work as thoroughly or completely as the system that corrects for location differences. Therefore, even though the representations used in mental rotation are orientation-specific, they may not be location-specific.

This possibility raises a more general issue about mental representations in imagery. Mental rotation experiments suggest that shape and orientation information are not factored apart in these representations. However, from the orientation experiments alone we cannot assume that *every* spatial property is integrated with shape information in image representations. In other words, these experiments by themselves do not imply that these representations are "analog" or "depictive" in every sense (Kosslyn, 1980). Visual information can be transformed in numerous ways so that shape and orientation information are still coupled but other spatial properties are changed or eliminated. To completely determine the nature of these representations, we must specifically determine how each type of spatial property is encoded in them, and whether or not it is factored apart from the representation of shape.

One potential example of the elimination of a spatial property involves the coding of size or scale. Size is a spatial property that is analogous to location in that a particular visual object can appear at many different sizes, depending on its distance from the viewer. The visual system must be able to identify the object regardless of these wide variations in size, and therefore size information may be factored out and separated from shape information at an early stage. If size is factored out of shape representations at an early stage, then response times for shape discrimination tasks should not depend on the size of the stimuli. However, the numerous size experiments cited previously have tested this notion using a methodology similar to that used by Cooper & Shepard. For certain shape discrimination tasks these experiments show a pattern of increasing response time with increasing size adjustment that is very similar to the pattern of orientation adjustment in Cooper & Shepard's experiment. Therefore these experiments suggest that size is treated similarly to orientation in image representations.

Given that orientation and size appear to be represented integrally with shape in visual image representations, it might seem reasonable to conclude that all spatial properties are represented integrally with shape in these representations. However, neuroanatomical and neurophysiological studies indicate that one region of visual cortex is dedicated to processing location and a separate region is dedicated to processing shape (Ungerleider & Mishkin 1982). If location is processed in a separate brain region from shape, then its representation is probably separate from the representation of shape. Because the representations used in mental rotation must include shape information, they might reside in the region that specializes in shape, and thus location information is likely to be factored out of them.

However, other evidence from imagery experiments suggests that location is important in image representations, and thus is probably not factored out. Farah (1985) asked subjects to image a large shape while performing a visual detection task. She found that subjects were better at detecting a stimulus if it appeared within the region covered by the imaged shape. If the location of an image affects the perception of a stimulus, then location must be part of the image representation. However, Farah's task is very different from the mental rotation task. She instructs her subjects to use imagery, and the shape they are imaging covers a large area. In following these instructions, her subjects might also be focusing visual attention on the area covered by the shape, thus enhancing their responses to stimuli that fall within this area. Farah and others

(Cave & Kosslyn, 1989) would argue that there is a crucial link between imagery and attention, and that the presence of attentional effects suggests that imagery is involved. Nevertheless, for the question of location specificity we need a demonstration that cannot be explained by attention.

Further evidence for the use of location in image representations comes from experiments demonstrating that the time to scan from one location to another increases with the distance scanned (Kosslyn, 1973; Kosslyn, Ball, & Reiser, 1978). If at any given time a subject is "examining" a particular location in an image, then it seems that location must be specifically encoded in an image representation. Perhaps instead, though, images are coded in a location-independent representation, and when subjects are instructed to focus on one end of an imaged object and then scan to the other end, they are successively loading information from different locations into the image representation, starting at one end and ending at the other. The increase in response time with longer distances would reflect the time necessary to load and unload more information to and from the image representation, and not the time to adjust location within the representation.

There is also a possibility that these different imagery tasks rely on different mental representations. One way in which the mental rotation task differs from Farah's experiment and the scanning experiments is that subjects in mental rotation experiments are not explicitly instructed to generate images. They devise their strategy spontaneously, without instructions or encouragement from the experimenter. Consciously generating an image of a scene might rely on different representations than spatial transformations required for normal visual recognition.

Other experiments have demonstrated that the time necessary for image scanning depends on the distance scanned, even if subjects are not specifically instructed to use images (Finke & Pinker, 1982; Finke & Pinker, 1983; Pinker, Choate, & Finke, 1984). In these experiments, subjects remembered a configuration of dots, and then judged whether the line extended from an arrow would intersect any of the dots. This task was designed to require the use of mental images, but it also specifically required the use of location information, because the location of each dot was crucial in determining the correct response. Thus, even if subjects had available a representation in which shape was coded independently of location, they would not have been able to use it in this task. One possibility is that in visual images, the representation of each visual object includes information about the relative locations of its different parts, but that the location of the object as a whole is not represented. In this case, Finke & Pinker's subjects might represent the entire dot pattern as a single object, so that the location of each dot would be preserved.

We need an experiment that tests whether location-independent image representations exist but that does not have the problems associated with these earlier experiments. Such an experiment must use a task in which subjects are not instructed to use images, and in which the location of a stimulus is not relevant to the response. For these reasons, Experiment 1 was designed to explore the importance of location information using a modification of Cooper & Shepard's basic mental rotation paradigm.

Experiment 1

Cooper & Shepard concluded that subjects can only generate the necessary mental representation to compare with the stimulus if they know all the necessary properties of the stimulus. The logic behind Experiment 1 relies on that conclusion. In Cooper & Shepard's experiments, the stimulus always appeared in the center of the display, so subjects always knew its location before it appeared. If location is coded in these representations in the same manner as orientation, then withholding location information should make it impossible for them to construct the representation beforehand. Without the representation, subjects will not be able to respond quickly to misoriented stimuli, even if they know the orientation and shape.

Method

Subjects. 17 subjects from the M. I. T. Department of Brain and Cognitive Sciences subject pool were tested and were paid for their services. Most were M. I. T. undergraduates, and their vision was normal or corrected to normal. One subject was rejected after being tested for reasons described later.

Apparatus. The experiment was controlled by an IBM PC/XT computer. Stimuli were displayed using EGA graphics on an NEC Multisync monitor. Subjects' responses were recorded with two microswitches, one for each hand, and a foot pedal.

Stimuli. Each test stimulus consisted of a single character, either the letter J, the letter R, or the numeral 4. These characters were chosen because they are distinct from their mirror-images, they are fairly complex, and they have few curved parts and thus are easily generated on the computer display. The stimuli were made with straight line segments, and gave the appearance of a bold, sans serif type. The stimuli appeared in eight different rotations and in both normal and mirror-reversed form. Each character was about 1.4 cm (1.6° of visual angle) in height. Figure 1 displays the characters used.

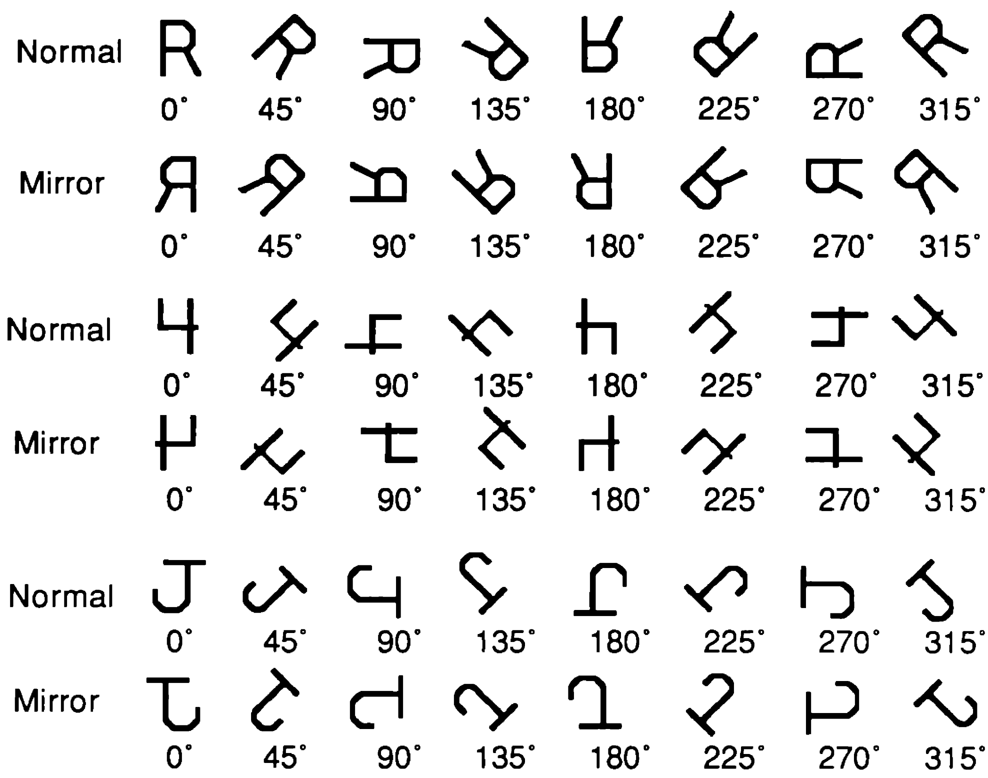


Figure 1: Stimuli, both normal and mirror-reversed, for all the orientations used in Experiment 1.

Each test stimulus was preceded by a cue appearing at the center of the screen. The cue was one of two types, as depicted in Figure 2. One type consisted of one of the three characters at one of the eight possible orientations. This type of cue informed the subject of both the shape and the orientation of the upcoming test stimulus. (Cooper & Shepard presented shape and orientation separately, to demonstrate that subjects could combine the two types of information. For the purposes of this experiment, it is not necessary to demonstrate that combination again. Therefore, we made the task easier for the subjects by presenting shape and orientation combined.) These cues were never mirror-reversed, and gave the subject no information about whether or not the test stimulus would be mirror-reversed. The second type of cue consisted of an arrow at one of the eight orientations. It revealed the orientation of the upcoming stimulus, but not its shape. The information provided by either type of cue was always correct: The orientation and shape never deviated from the values cued.

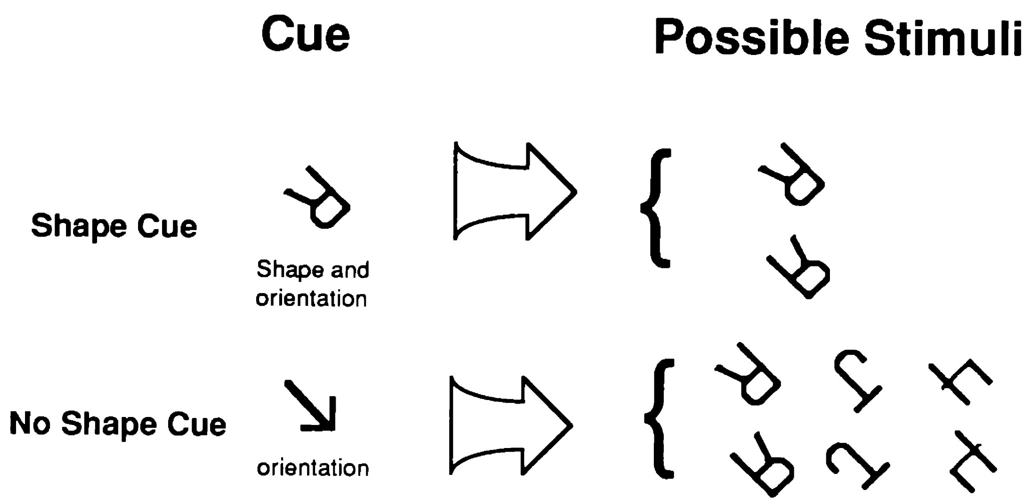


Figure 2: Examples of the two types of cue used in Experiment 1, along with the possible stimuli that could appear after them.

Procedure. The subject was seated in front of the CRT in a dimly lit room. A chin rest was used to maintain a constant viewing distance of about 50 cm. The subject was instructed to keep one hand on each of the response keys.

Each trial began with the presentation of a cue at the center of the screen. The subject was asked to study the cue and to press the foot pedal when ready to proceed. When the subject pressed the pedal, the cue immediately disappeared and the test stimulus appeared at one of four locations, as shown in Figure 3. Each of the four locations was 5.6 cm (6.4°) from the center of the screen. The test stimulus was one of the three characters, either normal or mirror reversed, at one of the eight possible orientations. The computer synchronized the onset of the test stimulus with the beginning of a video cycle, waited 120 msec, and removed it at the beginning of the next video cycle. This display time was too short to allow eye movements to the stimulus before it disappeared. The stimulus was a black figure on a white background, and when it disappeared the display was completely white, so that no residual image of the stimulus would persist on the display after it had been removed.

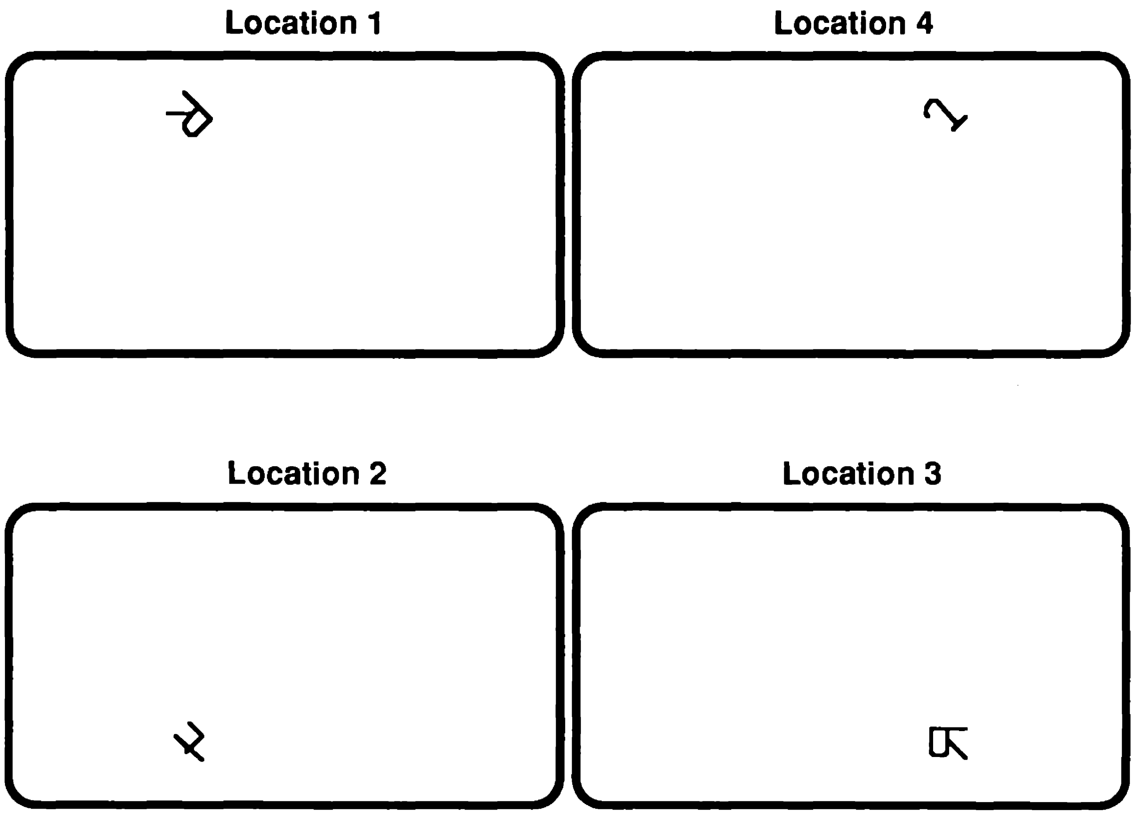


Figure 3: Examples of test stimuli at the four locations at which they could appear in Experiment 1.

The subject's task was to press the key under the dominant hand if the test stimulus was normal, and to press the other key if it was mirror-reversed. If the subject gave an incorrect response, the screen briefly flashed red and a buzzer sounded. The computer made a record of the error trials, and repeated each of them once at the end of the session.

Each possible combination of the two cue conditions, three shapes, eight orientations, four locations, and two response conditions (normal and mirror-reversed) was used, giving a total of 384 different types of trial. There were four instances of each type for each subject, not including those that were repeated because of errors. For each subject, the 1536 trials were arranged in a different random order, with all the different trial types intermixed. Each subject required three different testing sessions to complete all the trials, with each session lasting between 40 and 60 minutes.

Results

During the testing of one of the subjects, the experimenter noticed that the subject was often pressing the foot pedal immediately after the cue appeared. When questioned, the subject claimed that she was not using the cues at all. We thus decided to omit her data from the analyses, leaving a total of 16 subjects.

Response times. The response time data were submitted to an analysis of variance (ANOVA) with cue type (shape or no-shape), orientation, handedness (normal or mirror-reversed), location, and shape (R, J, or 4) as factors. Subjects made incorrect responses on 4% of the trials (including those repeated because of earlier errors), and all of these trials were excluded from the analysis. The response times from both cue conditions are presented in Figure 4 as a function of orientation. In general, subjects responded much more quickly when the shape was cued, $F(1,15) = 31.8$, $p < .001$. If subjects are able to prepare images only when they know the shape beforehand, then moving the orientation further from upright should not increase response times in the shape cue condition in the way that it does in the no-shape cue condition. A contrast revealed that the linear increase with orientation difference was indeed much stronger in the no-shape cue condition than in the shape cue condition, $F(1,105) = 135.9$, $p < .001$. The difference between the two conditions is clear in Figure 4, and is very similar to that found by Cooper & Shepard. Thus subjects appear to be able to generate and use images in this task, even without knowing the correct location in advance.

Because subjects were apparently able to prepare an image in the shape cue condition and not in the the no-shape cue condition, we used two other ANOVAs to examine the results of the two conditions separately. Not surprisingly, a contrast in the no-shape cue analysis established a strong linear increase in response time with the deviation of the orientation from upright , $F(1,105) = 285.9$, $p < .001$. Responses were slower when the stimulus was mirror-reversed, $F(1,15) = 22.3$, $p < .001$, probably in part because these responses were made with the nondominant hand. The shape R elicited particularly fast responses, $F(2,30) = 6.0$, $p < .01$. There were no apparent overall differences among responses to the stimuli at the four different locations, $F < 1$.

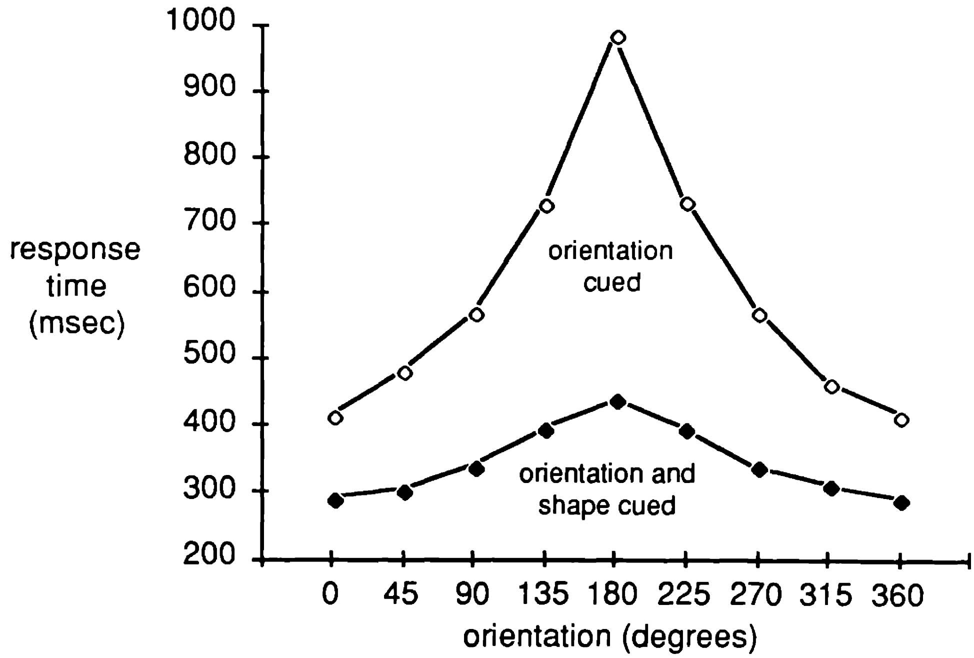


Figure 4: Response times from the shape cue and no-shape cue conditions of Experiment 1.

The no-shape cue condition also produced an unexpected but interesting result. In this condition, the cue was always an arrow at the center of the screen. Because the four possible stimulus locations surrounded the location of the the arrow, whenever the arrow was at one of the four diagonal orientations it pointed directly at one of the four possible locations. Subjects were told that this arrow represented the orientation of the upcoming stimulus, and the arrow gave no useful information about the stimulus location. Nevertheless, subjects responded more quickly when the stimulus appeared at the location pointed to by the arrow, $F(21,315) = 2.5$, $p < .001$. For instance, when the arrow was at 45°, it pointed toward location 4. Once the main effect of orientation is removed from the data, response times for stimuli at location 4 tend to be faster when the orientation is near 45°, and then to be slower when the orientation is 180° away, at 225°. This pattern can clearly be seen in Figure 5. In this figure, the main effect of orientation has been removed, and the data for each of the four locations have been shifted so that in each case the mean for those trials in which the arrow was pointing directly at that location is at the center of the graph, and the mean for those trials in which the arrow was pointing directly away from that location is at either edge of the graph. For each of the four locations, the response times are generally lower at the center point, and higher at the edges, illustrating that the response time increases as the arrow points farther away from the stimulus location. Perhaps the large arrow is suggestive enough that subjects allocate visual attention according to its direction. A second unexpected result from the no-shape cue ANOVA was that responses to the shape J were generally slower for orientations near 180°, $F(14.210,) = 3.0$, $p < .001$.

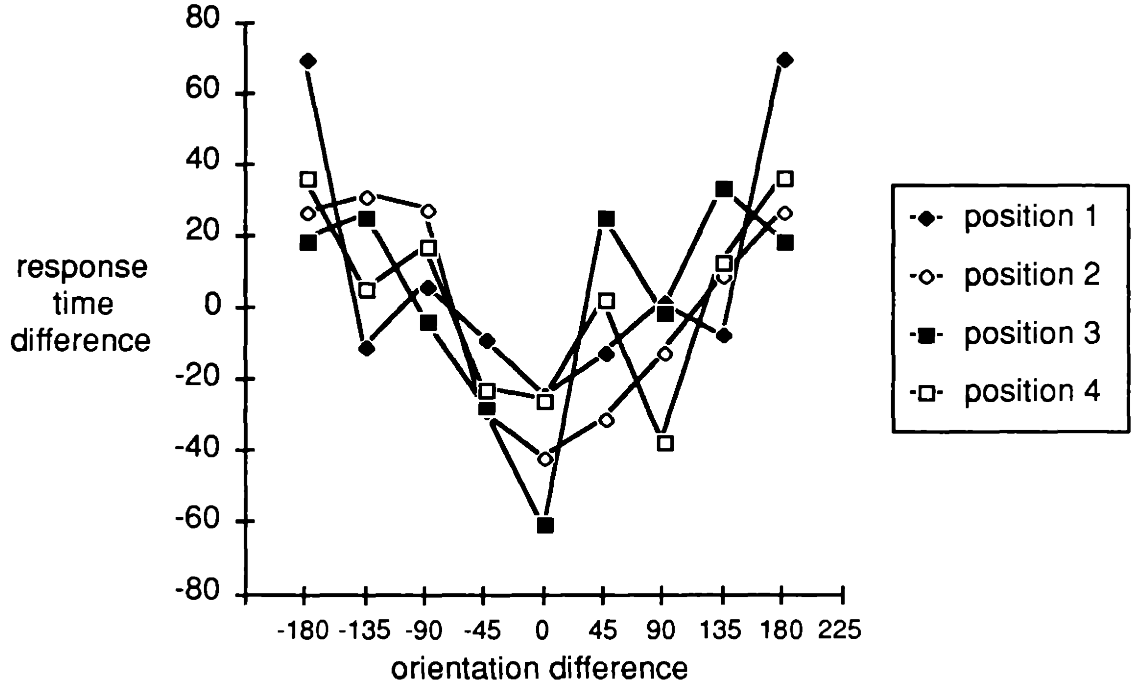


Figure 5: Response times organized by difference between cued orientation and orientation of stimulus location in relation to fixation. Main effect of orientation has been removed.

The overall analysis showed that the linear increase in response time with orientation difference was much smaller when the shape was cued than when it was not. Nevertheless, a contrast in the shape cue ANOVA showed that the increase was still significant, $F(1,105) = 113.8$, $p < .001$. This rise is apparent at the bottom of Figure 4. As with the no-shape cues, responses were slower to mirror-reversed stimuli, $F(1,15) = 59.3$, $p < .001$.

The shape cue analysis also produced a handful of unexpected results. Responses to mirror-reversed stimuli were especially long for orientations near 180˚, $F(7,105) = 3.0$, $p < .01$. The shape 4 seemed to elicit slower responses, $F(2,30) = 11.0$, $p < .001$, at least when the stimulus was mirror-reversed, and the shape R apparently produced faster responses among the normal stimuli, $F(2,30) = 15.8$, $p < .001$. The shape cue condition did not show the relationship between cued orientation and location found in the no-shape cue condition, $F < 1$, presumably because the shape cue was always a letter or digit, and not an arrow. However, the advantage for normal over mirror-reversed stimuli tended to increase when either end of the stimulus shape axis pointed toward the fixation cross, especially if the stimulus appeared in one of the two locations above the fixation cross, $F(21,315) = 3.2$, $p < .001$. There were no other significant interactions in either the shape cue or the no-shape cue analysis ($p > .05$ in all cases).

The overall analysis reiterated that subjects responded relatively quickly to the shape R when they did not know the shape in advance, and responded relatively slowly to the shape 4 when they did know the shape, $F(2,30) = 3.8$, $p < .05$. As mentioned before, responses to the shape J were particularly slow for orientations near 180° when the shape was not known, $F(14.210) = 2.9$, $p < .001$. The advantage that comes when the cue is oriented towards the stimulus occurred only when the cue was an arrow, and not when it was a letter or digit, $F(21,315) = 1.9$, $p < .01$. There were no other significant effects in the overall analysis that did not also appear in one of the two smaller analyses ($p > .05$ in all cases).

An examination of the data from the one rejected subject revealed that she generally responded faster after shape cues than after no-shape cues. However, with both types of cue her response times increased substantially with orientation, suggesting that she was not using the shape cue to form an image, and was therefore forced to rotate every stimulus. This pattern is consistent with her description of her strategy.

Testing for hemispheric differences. Farah (1986) demonstrated an advantage for the left hemisphere over the right at using an image in a visual discrimination task. Because the stimuli in Experiment 1 were presented on either side of the visual field and were presented too quickly for a saccade, we can perform contrasts to test for a left-hemisphere advantage in this mental rotation task. In the shape cue analysis, response times were significantly faster for the two right-hemifield (left-hemisphere) locations, $F(1,45) = 4.9$, $p < .05$. There was no hint of an advantage with the no-shape cues, $F < 1$, just as would be expected if the advantage were due entirely to imagery. However, in the overall analysis, the advantage for the right-hemifield locations was not significantly larger with the shape cues than with the no-shape cues, $F(1,45) = 1.6$, $p > .2$. Thus, altogether these results suggest that the left hemisphere enjoys an advantage for this mental rotation task, but the evidence that this advantage is entirely due to imagery is not particularly strong.

Note that Farah (1984, 1986) claims that the left hemisphere should be better at *generating* visual images. In this task, the shape cue consists of the correct shape at the correct orientation. If subjects can retain an image of the cue and adjust its location after the stimulus appears, then they do not need to generate an image from memory. The same is true for Farah's (1986) experiment in which she originally demonstrated the left-hemisphere advantage. More work is necessary to determine whether the left hemisphere enjoys an advantage for generating images, adjusting their location, or both.

Error rates. To test whether any of the critical results described above could be attributed to speed/accuracy trade-offs, we analyzed the error rates from Experiment 1. Data from both the shape cue and no-shape cue conditions were submitted to an ANOVA using the same factors as in the combined analysis of response times. Everything found in the error rates was consistent with the response time data. Subjects made more errors as the orientation difference increased, $F(1,105) = 103.4$, $p < .001$, especially with no-shape cues, $F(1,105) = 39.6$, $p < .001$. Subjects made fewer errors when the shape was cued beforehand, $F(1,15) = 27.8$, $p < .001$. They made fewer errors with the letter R, and more with the numeral 4, $F(2,30) = 6.5$, $p < .01$. As with the response times, the normal stimuli enjoyed an advantage over the mirror-reversed stimuli when either end of the stimulus shape axis pointed toward the fixation cross, $F(21,315) = 2.1$, $p < .005$. No other main effects or interactions were significant in the error rate analysis ($p > .05$ in all cases). Because all of these effects correspond to effects in the response time data, there is no evidence of any speed/accuracy trade-off.

Discussion

The results from this experiment are strikingly similar to those from Cooper & Shepard's experiment. Note also that the peaks of the response time distributions in this experiment are also about the same as Cooper & Shepard's: In both experiments, response times for 180° stimuli are just over 400 msec when both shape and orientation are known, and about 1000 msec when only orientation is known. The similarity between the results from Experiment 1, in which subjects do not know the location of the stimulus in advance, and those from Cooper & Shepard's experiment, in which subjects do know the location, leads to the conclusion that knowing the location of a stimulus makes at most a small difference in using an image to make a mirror-reversal judgment. Perhaps the fact that location is not more important in these representations should not be surprising, because this property makes these representations much more useful in a world in which objects can often appear at any location in the visual field.

The large difference in the effect of orientation between the shape cue and no-shape cue conditions makes it clear that the stimuli are processed very differently in the two conditions. Nevertheless, the increase in response time with orientation difference in the shape cue condition is also significant, even though it is much smaller than in the no-shape cue condition. Subjects are likely to be occasionally rotating stimuli in this condition even when they know the shape, either because they have forgotten the cue or because they want to perform an additional test to be sure of their response. If the stimulus is mirror-reversed, it will not match the image representation that the subject has prepared beforehand. We might expect that subjects would be more likely to perform an extra test in this case, and the data are in accordance with this suggestion.

In this experiment, we used only half the number of shapes that Cooper & Shepard used in their experiment. Because our results are so similar to theirs, it appears that this variation had little effect on the general outcome of the experiment. Obviously, if only a single shape were used, subjects would always know the shape before the stimulus appeared, and once the orientation was cued they would generally be able to prepare an image in advance. Using three different shapes, however, appears to be adequate for demonstrating mental rotation.

Experiment 1 demonstrates that location differences can be handled quickly and easily in mental rotation, but it does not give a definitive answer to the question of location-specificity in the mental representations that are used in this task. Location differences could be handled in two different ways. In the shape cue condition, the stimulus might be normalized or otherwise recoded into a location-independent form, and then compared against a location-independent image representation. On the other hand, when the mental image is prepared before the stimulus appears, it might be represented at a particular location, probably corresponding to the center of the display. Once the stimulus appears, the location of the image could then be adjusted so that it matches the stimulus location, and it could then be compared with the stimulus. Because each of the four stimulus locations in Experiment 1 is the same distance from the center, the time necessary to move the image to each location would be the same. We cannot compare our results and those of Cooper & Shepard with enough precision to measure whether our subjects required extra time to adjust the represented location. However, the similarity between the two sets of results suggests that if location adjustment is necessary, it must be done very quickly.

Experiment 2

Experiment 2 is designed to determine whether the representations used in mental rotation are in fact location-independent. Testing for location effects is somewhat more complicated than testing for orientation effects. Measuring orientation adjustment is relatively easy because the shapes have a standard orientation associated with them. Whenever a stimulus appears at a nonstandard orientation, an adjustment will be necessary, unless the subject knows the shape and the orientation long enough in advance to prepare an image representation for comparison. However, objects do not have standard locations associated with them, and thus many of the types of circumstances that require orientation adjustment may not require location adjustment. To measure location adjustment, therefore, we must induce subjects to create the appropriate image by telling them the shape and orientation of the upcoming stimulus, and by leading them to believe that it will appear at a particular location. Then we can measure the "movement" of the image to another location.

There are other complications in measuring location adjustment. In order to maximize the possible distance between cue and test stimulus, these shapes will be positioned at the far sides of the display. Thus, they will be subject to less thorough processing because of the decrease of acuity with retinal eccentricity.

As in Experiment 1, all stimuli will appear the same distance from the fixation cross so that there are no substantial acuity differences. Additionally, by presenting stimuli at different locations, we run the risk of introducing eye movements, which would add to the response times and obscure the important effects. Eye movements were not a problem in Experiment 1, because the cue always appeared at the center of the screen. The subjects did not know where the stimulus would appear, and it disappeared too quickly for them to make a saccade. In this experiment, subjects must know in advance where the stimulus is likely to appear; therefore we must prevent them from saccading to that location.

Cooper and Shepard showed that the amount of time necessary to adjust orientation varied with the amount of adjustment necessary. The current experiment will test for a similar pattern in location adjustments by varying the amount of adjustment necessary from trial to trial. Looking for processing differences at different locations will be complicated by the allocation of visual attention. Attention experiments have shown that subjects respond more quickly to stimuli that appear at an expected location (Posner, Nissen, & Ogden, 1978; Posner, Snyder, & Davidson, 1980), and that, at least in come circumstances, response time tends to increase with larger distances between the expected location and the actual location (Downing & Pinker, 1985; Rizzolatti, Riggio, Dascola, & Umiltá, 1987). To ensure that any distance effect is due to the adjustment of image representations and not to general attentional factors, we must compare response times with and without image representations. Because subjects cannot create an image without knowing the shape, Experiment 2 will have two different conditions, with the same sort of shape cues and no-shape cues used in Experiment 1. For clarity, the condition with shape cues will now be referred to as the image condition, and the condition with no-shape cues will be called the no-image condition.

Method

Subjects. This experiment required subjects to fixate at one location on the display while attending to a stimulus at a distant location. Additionally, because a pupil tracker was monitoring eye position, subjects were required to keep their eyes open from the beginning to the end of each trial. When they began the first session, most subjects were not able to successfully complete many trials. Most of them, however, improved with practice, and a total of 15 successfully completed the entire experiment. A similar number of subjects began the experiment but quit after a significant amount of practice, either on their own or at the suggestion of the experimenter. All subjects were from the M. I. T. Department of Brain and Cognitive Sciences subject pool, and all were paid for their time, whether or not they completed the experiment. Most were M. I. T. undergraduates, and their vision was normal or corrected to normal. These subjects did not participate in the previous experiment.

Apparatus. The computer, video display, and response keys used in this experiment were the same types used in Experiment 1. An ISCAN model RK-416 pupil tracker was used to monitor eye movements. The eye tracker received an image of the subject's left eye from an RCA TC2000 video camera with a close-focus lens and an infrared filter. A table light fitted with an infrared filter illuminated the subject's eye, and a chin rest and forehead restraint held the subject's head in place.

The pupil tracker received a video image of the subject's left eye from the camera 60 times each second. In each video image, the pupil tracker used an algorithm implemented in hardware to locate the pupil by identifying a large dark region. It then calculated the center of this region, and transmitted the horizontal and vertical coordinates of the center's location within the video image to the computer. When the subject steadily fixated on a single location, there was a small amount of variation in the coordinates from the pupil tracker, due mainly to small changes in the video image from cycle to cycle. The program controlling the experiment recorded the eye position once at the beginning of each trial, and then monitored the eye position continuously until the subject responded. If the distance between the original recorded position and the current eye position ever exceeded a threshold, the trial was aborted. Before subjects were tested, we determined the lowest level at which we could set the threshold without producing an inordinate number of false alarms. The threshold value we used generally allowed for the detection of eye movements of 2.5° of visual angle or greater.

Stimuli. As in Experiment 1, each stimulus consisted of a single character, either the letter J, the letter R, or the numeral 4. As before, the characters could be normal or mirror-reversed. This experiment required that a number of different factors be varied and thus required a large number of different types of trials. Therefore, only four orientations were used, 45°, 135°, 225°, and 315°.

As in Experiment 1, each test stimulus was preceded by either a shape cue or a no-shape cue. Each shape cue consisted of a character at a particular orientation. In this experiment, we did not use a large arrow as the no-shape cue as we did in Experiment 1, so that subjects would be less likely to shift attention in the direction of the arrow, as they seemed to do in that experiment. Instead, each no-shape cue was a rectangle the same size as the characters, with a small arrow indicating its top, as shown in Figure 6. As with the shape cue, the orientation of the box corresponded to the orientation of the upcoming test stimulus.

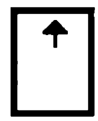


Figure 6: The no-shape cue used in Experiment 2.

For the duration of each trial, a small fixation cross occupied the center of the screen. Each of the cue and test stimuli was positioned on an imaginary circle that was centered on the fixation cross, so that they were all 5.6 cm (6.4°) from the fixation cross. The cue could appear at one of two locations, either to the far left or the far right of the display. (We used only two different cue locations because of the large number of different types of trials necessary for this experiment.) The cue was not vertically aligned with the fixation cross; instead, its vertical location was slightly higher, as shown at the top of Figure 7. (A line connecting the cue and the fixation cross would intersect a horizontal line with an angle of 12°.) This displacement was to ensure that test stimuli appearing at the cued location would not receive any benefit or cost that might come from being aligned with the fixation cross. The test stimulus could occur at the same location as the cue, or at one of the locations 20°, 95°, or 160° around the imaginary circle in either direction from the cued location, yielding distances of 1.9 cm, 8.3 cm, and 11.0 cm between cue and test stimulus.

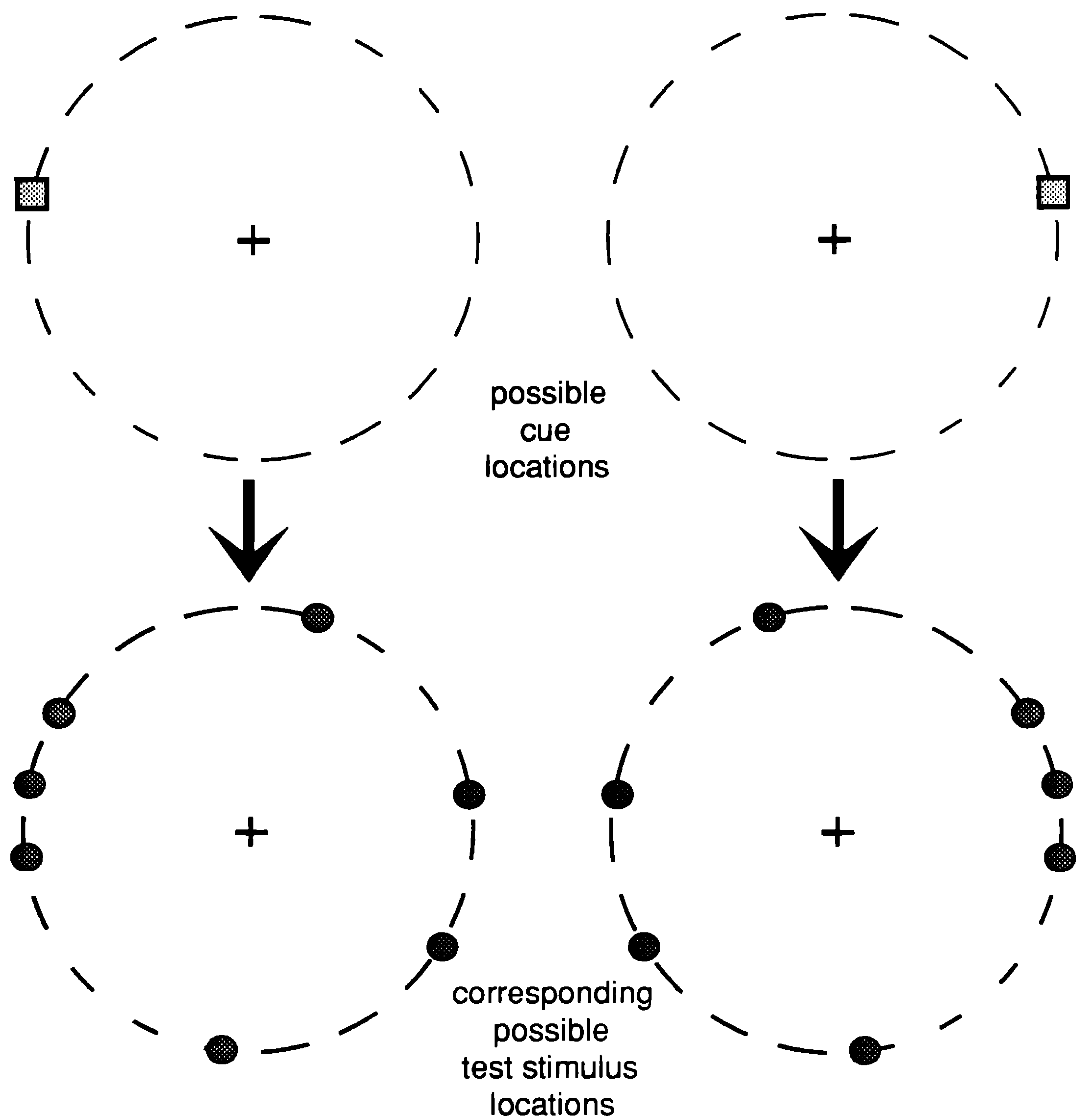


Figure 7: The top two figures illustrate the two possible cue locations relative to the fixation cross. The bottom two figures illustrate the seven possible test stimulus locations that correspond to each of the cue locations.

Procedure. As in Experiment 1, the subject was seated in front of the CRT in a dimly lit room. The subject was instructed to keep one hand on each of the response keys.

Each trial began with the presentation of the small fixation cross at the center of the display. The cross remained on the screen until the end of the trial, and subjects were instructed to keep their eyes fixed on it until then. The eye position was recorded 1500 msec after the fixation cross appeared, and it was monitored for the rest of the trial. If the computer detected a substantial eye movement at any time during the trial, a buzzer sounded, the screen flashed red, and the trial was aborted.

The cue appeared just after the eye position was recorded. Because subjects did not know where the cue would appear until after the eye monitoring began, they could not begin the trial with their eyes fixed on the cue. The cue remained on the screen for 700 msec, and then disappeared. In the image condition, the cue provided information about the shape, orientation, and location of the test stimulus that would appear soon afterwards; in the no-image condition, the cue provided information about only the orientation and location. The shape information (when it was available) and the orientation information were always accurate. The location information, however, was only accurate on half the trials. In the other half of the trials, the location was evenly distributed over the other six possible locations. Because of the disproportionately large number of stimuli at the cued location, subject were better off to position images at the cued location than at any other location. The instructions stated that the cue would often occur at the same location as the test stimulus, but there was no mention of imagery or image position.

The test stimulus appeared 1500 msec after the cue disappeared. As in Experiment 1, the computer waited for the beginning of a video cycle, presented the test stimulus, waited for an interval of 120 msec, and then removed it at the beginning of the next video cycle. As before, subjects pressed the key under the dominant hand if the test stimulus was normal, and the other key if it was mirror-reversed. If the subject pressed the wrong key, the screen flashed blue and a buzzer sounded (using a different tone than that used to indicate an eye movement). Error and eye movement trials were saved and were repeated at the end of each block of 128 trials, and this process continued until all trials in that block had been completed correctly. After every 32 trials, the computer stopped presenting trials and the subject was allowed to take a break.

With two cue types, three shapes, four orientations, two responses (normal and mirror-reversed), there were a total of 48 trial types for each location. For each cue location, six stimuli occurred at the same location as the cue, and one appeared at each of the six possible uncued locations. Because there were two different cue locations, there were a total of 1152 trials for each subject, not including those that were repeated because of errors. A new random order was generated for each subject, with all the different trial types intermixed. Each of these subjects generally required about four testing sessions, each lasting for an hour or less.

Results

Response times. The response time data were submitted to an ANOVA with cue type, orientation, handedness (normal or mirror-reversed), shape (R, J, or 4), distance, cue hemifield (left or right), and placement around the circle (clockwise or counterclockwise, which was irrelevant for stimuli at the cued location) as factors. Subjects made incorrect responses on 2% of the trials. As described above, incorrect trials were repeated at the end of the block, and only response times from correct trials were included in the analysis.

The main purpose of Experiment 2 was to measure the effects of distance on the use of images. A contrast revealed that response times generally increased with the distance between cue and test stimulus, $F(1,42) = 96.6$, $p < .001$. More importantly, a second contrast showed that this increase was greater in the image (shape cue) condition than in the no-image (no-shape cue) condition, $F(1,42) = 12.3$, $p < .005$. Figure 8 shows the data from these two conditions, along with the best-fitting regression line for each. In the no-image condition, the increase with distance probably reflects the attentional effects described earlier. The slope in the image condition is almost twice as large, suggesting that subjects are moving the image from the cued location to the stimulus location.

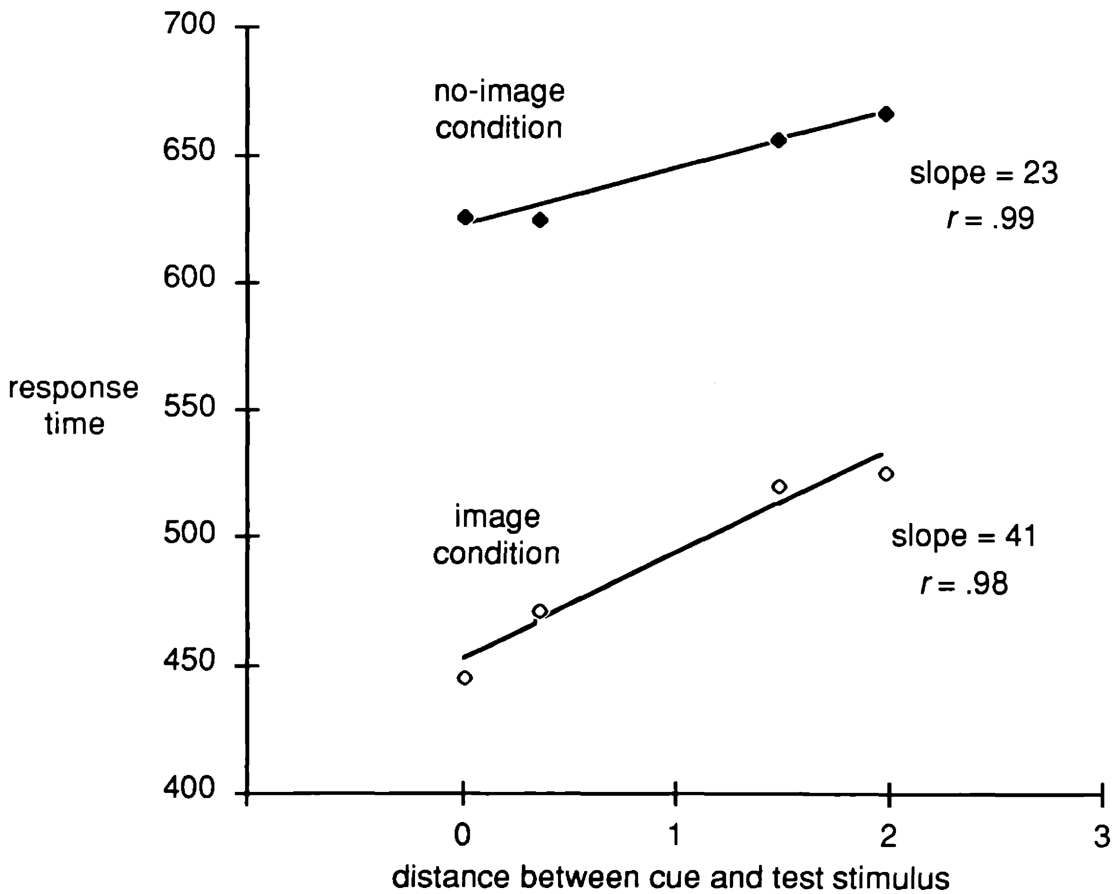


Figure 8: Response time as a function of distance between cue and test stimulus for both image and no-image conditions. The unit of distance is the radius of the imaginary circle on which the test stimuli fell. The *r* values give the correlation between mean response time and distance for each of the two conditions.

As in Experiment 1, subjects responded more quickly when they knew the shape of the stimulus beforehand, $F(1,14) = 129.0$, $p < .001$. As expected, contrasts showed that responses were faster for the two orientations near 0° than for the two near 180°, $F(1, 42) = 160.8$, $p < .001$, and that the advantage for the easier orientations was greater when the shape was unknown, $F(1,42) = 54.2$, $p < .001$. These results indicate that subjects were using the shape information to make images, and that these images helped them with the more difficult orientations, just as in Experiment 1.

If subjects always move an image to the stimulus location, wherever it might be, then once the image is in place, subjects should be able to respond quickly to any orientation, regardless of the distance the image has moved. When we tested this claim, however, we found an interesting result. For each distance in both the image and no-image conditions, we calculated the response time difference between the two easy orientations and the two orientations. The results are shown in Figure 9. A contrast confirms what is clear in the figure: There is a linear increase in the orientation difference that is limited to the image condition, $F(1,126) = 4.3$, $p < .05$. This pattern is not necessarily inconsistent with the claim that subjects move images to the stimulus location. The presence of a small but significant orientation effect in the shape cue condition of Experiment 1 indicates that even when subjects have enough information to create an image in advance, they sometimes decide to rotate the stimulus. Perhaps they occasionally lose the image before they can compare it against the stimulus. The longer the distance from the cue to the stimulus, the farther the image must be moved before it can be compared with the stimulus. Thus with longer distances, the image must be maintained longer is is more likely to be lost. Additionally, the longer distance means that the subject must work harder to use the image, and it is therefore more attractive to abandon the image and rotate the stimulus instead. Therefore, subjects are likely to rotate the stimulus more often with longer distances, and when the response times are averaged there will be a larger orientation effect with longer distances.

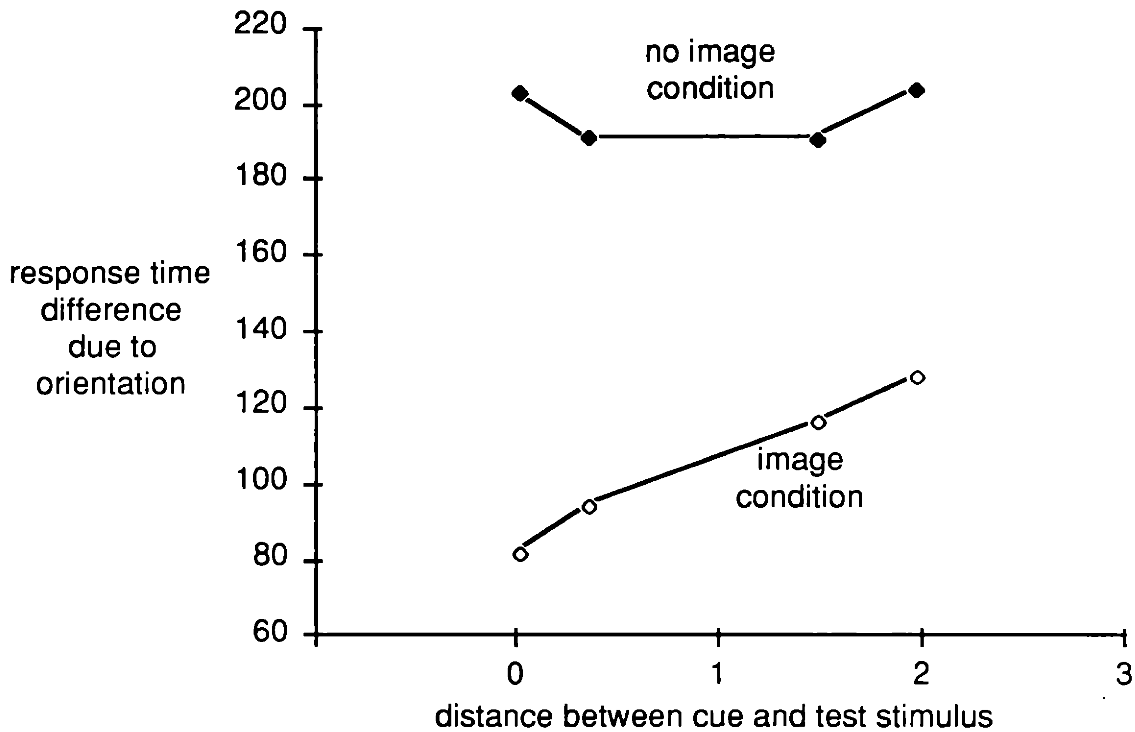


Figure 9: The difference between the mean response times for the two difficult orientations (near 180°) and the two easy orientations (near 0°).

Once again, subjects responded more slowly to mirror-reversed stimuli, $F(1,14) = 29.3$, $p < .001$. Responses were faster for the shape R and slower for the shape 4, $F(2,28) = 16.3$, $p < .001$, much as they were before. Neither cue hemifield nor placement direction (clockwise or counterclockwise) exerted a measurable influence on response time, $F < 1$ in both cases.

The analysis produced a number of additional results that are not directly relevant to location adjustment in image representations, but may be interesting for what they reveal about other aspects of these representations. Responses to mirror-reversed stimuli were impeded more by the difficult orientations than were responses to normal stimuli, $F(3,42) = 7.5$, $p < .001$, but only if the shape was known, $F(3.42) = 4.4$, $p < .01$. A similar pattern appeared in the shape cue ANOVA of Experiment 1, but not in the no-shape cue ANOVA. Tarr & Pinker (1989) provide a possible explanation for this pattern, based on the fact that subjects have little experience viewing mirror-reversed characters, but a huge amount of experience viewing normal characters. Usually the normal characters appear at the standard orientation, but subjects probably see them often enough at other orientations near the standard to form mental representations of them at those orientations. These representations allow subjects to recognize tilted characters directly, without rotating them. Because they encounter mirror-reversed characters less often, they almost never see them at nonstandard orientations, and therefore only form representations of them at the standard orientation. When a tilted mirror-reversed character appears, subjects cannot recognize it directly, and must rotate it. An alternative explanation is based on the idea that subjects always rotate stimuli when they are not given the shape, and occasionally rotate stimuli as an extra check when they are given the shape. When subjects use the shape information to prepare an image beforehand, a mirror-reversed stimulus will not match the image. If subjects are more inclined to perform an extra check after a mismatch than after a match, then when response times are averaged there will be a larger orientation effect for the mirror-reversed stimuli than for the normals. When the shape is unknown, all stimuli are rotated, and the orientation effect is equally large for normal and mirror-reversed stimuli.

For some reason, the variation in response time across different distances was generally greater for mirror-reversed stimuli than for normal stimuli, $F(3,42) = 7.7$, $p < .001$. There were ten other significant interactions ($p < .05$), which is not surprising. Given that there are seven factors in this analysis and

127 main effects and interactions, there are that number of chances for spurious significant effects. None reached the significance level of the effects reported here ($p > .01$ in all cases), and none appeared directly relevant to the questions at hand.

Crossing the Vertical and Horizontal Meridians. Before going on, we must investigate an alternative explanation for the response time differences that are attributed to distance between the cued location and the stimulus location. Experiments in visual attention have demonstrated that response times are raised when a stimulus is located on the opposite side of the vertical or horizontal meridian from the cue that precedes it (Downing & Pinker, 1985; Hughes & Zimba, 1985; Hughes & Zimba, 1987; Rizzolatti, Riggio, Dascola, & Umiltá, 1987). Perhaps stimuli that are farther from the cued location require more time only because they are more likely to be in a different quadrant than the cued location. Although this experiment was not specifically designed to test this hypothesis, we can test it by first comparing response times for pairs of locations that are in different quadrants but at the same distance from the cued location, and then by comparing location pairs that are in the same quadrant but at different distances from the cued location.

To test whether response time increases with meridian crossings in imagery, we must identify one stimulus location that is on the same side of a meridian as the cue, and a corresponding location on the other side of the meridian that is the same distance away from the cue. Two such location pairs are illustrated in Figure 10. In both cases, one stimulus is on each side of the horizontal meridian. Configurations with the cue on the left of the display are used as examples in Figure 10, although in half the trials the cue was on the right. There was another location pair that was not used because one location was on the opposite side of the horizontal meridian from the cue and the other was on the opposite side of the vertical meridian. If we are to be sure that any effect of meridian crossing in these comparisons is due to imagery and not attention, then we must test not just the difference associated with the two locations, but rather the variation in this location difference between the image and no-image conditions.

Pairs of Stimulus Locations at the Same Distance from the Cued Location but Within Different Quadrants

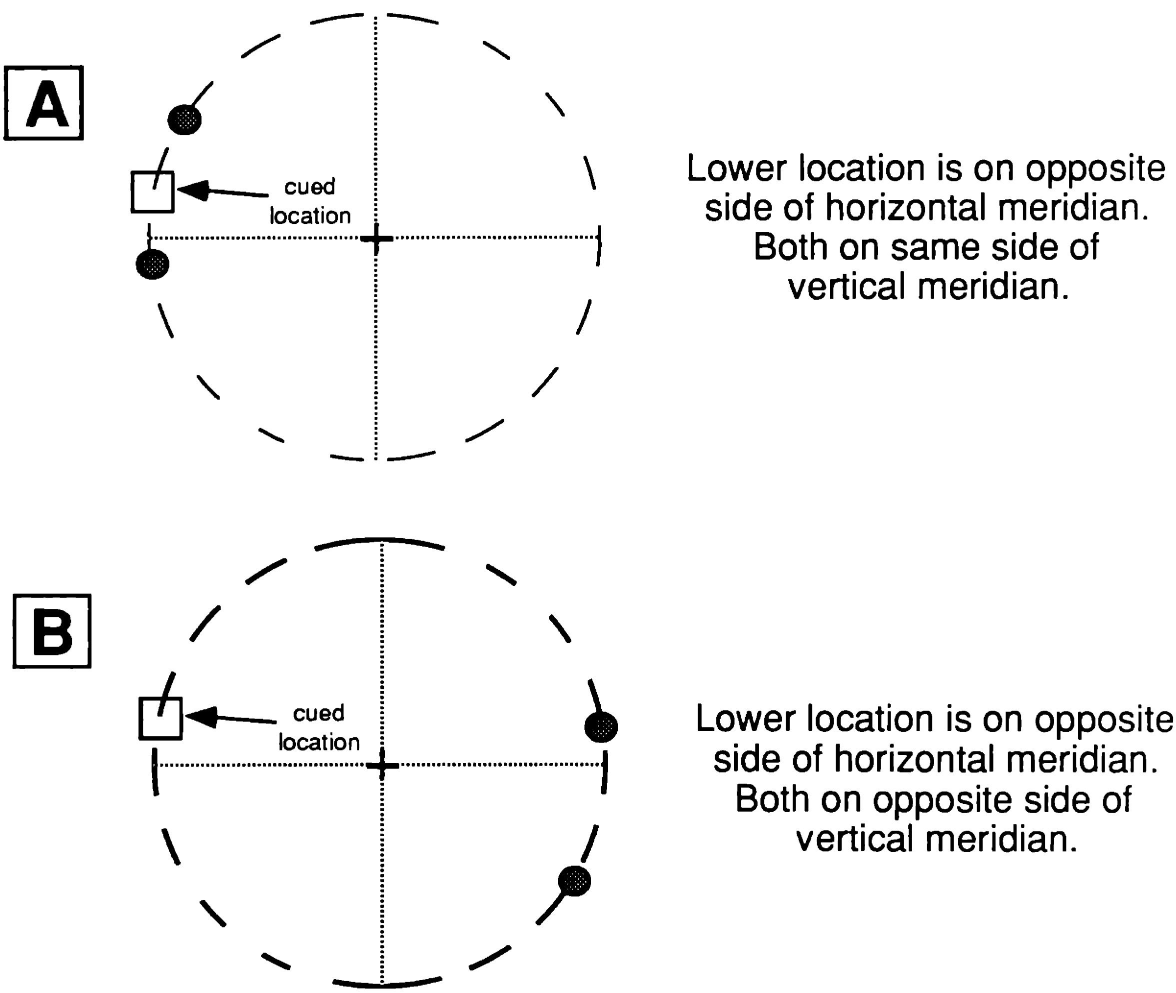


Figure 10: In order to test whether response time increases when an image must cross the horizontal or vertical meridian, we compared

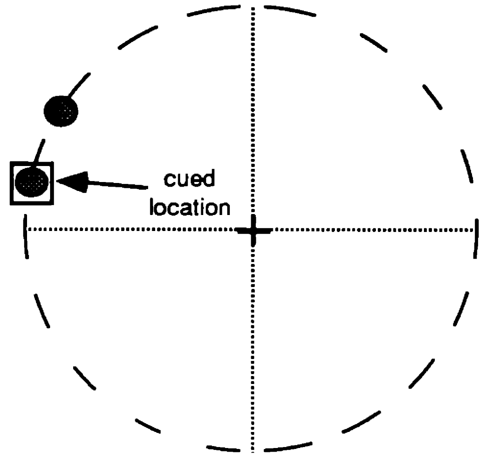
response times for the two pairs of locations illustrated above. For each pair, the two locations are in different quadrants of the visual field, but are both at the same distance from the cued location.

For the first location pair, presented in Figure 10a, the response time was no higher when the stimulus occurred on the opposite side of the horizontal meridian from the stimulus. (The response time was very slightly less, in both image and no-image conditions.) For the second pair, presented in Figure 10b, response time increased by 14 msec in the image condition when the stimulus occurred on the opposite side of the horizontal meridian. However, the no-image condition yielded a difference of 15 msec, and thus the response time difference must be due to something other than the movement of an image. The difference might be due to the attentional factors demonstrated by Downing & Pinker, Hughes & Zimba, and Rizzolatti *et. al.* Given that there was no difference in the first location pair, however, it is perhaps more prudent to attribute the difference to the fact that one location is almost aligned horizontally with the cued location, while the other is not.

Thus these comparisons yield no evidence that response time increases when an image and stimulus are in different hemifields. We can now look for evidence that the response time differences are due to distance and not meridian crossings by comparing location pairs that are in the same quadrant but are at different distances from the cued location. There are three different pairs of stimulus locations in this experiment that meet these criteria. They are illustrated in Figure 11. As before, because we are interested in the effects of image location rather than visual attention, we must compare differences between image and no-image conditions.

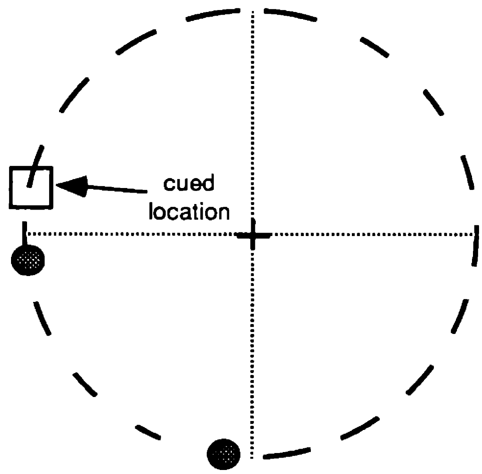
Pairs of Stimulus Locations Within the Same Quadrant but Differing in Distance from the Cued Location

A



Both in same quadrant as cued location.

B



Both on same side of vertical meridian as cued location but on opposite side of horizontal meridian.

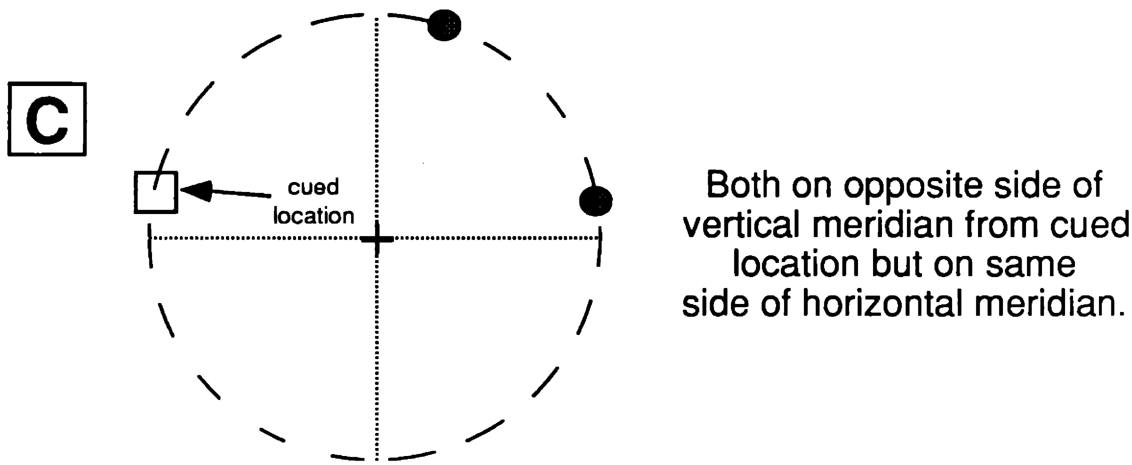


Figure 11: In order to test whether the response time increase in Experiment 2 could be attributed to distance, we compared response times for the three pairs of locations illustrated above. For each pair, the two locations are in the same quadrant of the visual field, but at different distances from the cued location.

In the location pair depicted in Figure 11a, both locations are in the same quadrant as the cue, and one location is the cued location itself. With this pair, there was a difference of 27 msec in the image condition, and almost no difference in the no-image condition: Response times were higher when an image must be moved from one location to another, $F(1,98) = 3.4$, $p < .05$.[1] However, there might be a special advantage when the test stimulus occurs at exactly the same location as the image. A better test would use two locations such as those depicted in Figure 11b, neither of which is the cued location. In this pair, both locations are in the quadrant below the quadrant occupied by the cue. Thus, they are both on the opposite side of the horizontal meridian from the cue, but on the same side of the vertical meridian. In this case, there was a 50

[1] In these contrasts we are specifically testing for an increase that was greater in the image condition, and thus we can use a one-tailed test. The p values will be half as large as for a two-tailed test. Additionally, because these contrasts involve a combination of different factors and interactions from the overall analysis with different error terms, the error terms used in the contrasts were obtained by pooling the error terms from the relevant interactions in the overall ANOVA, according to the procedure described by Rosenthal & Rosnow (1985) chap. 6.

msec difference in the image condition, and only a 24 msec difference in the no-image condition. As with the first pair, this interaction was significant, $F(1,84) = 2.9$, $p < .05$, and thus adds additional weight to the claim that response time increases with distance, regardless of the relative location of the meridians. In the final pair, depicted in Figure 11c, both locations are on the opposite side of the vertical meridian from the cue, but are on the same side of the horizontal meridian. In this case, there was no measurable increase in response time with distance in either the image or no-image conditions. (In both cases the response time was very slightly lower for the longer distance.) Because of the geometry of the imaginary circle, the distance between each of these locations and the cued location is much less than for the second pair, and thus if response time depends on distance between image and stimulus, we would expect the difference between these two locations to be smaller and more difficult to measure. Therefore the lack of a detectable difference between these two locations is not too surprising.

Obviously, these tests are less than perfect. A firm conclusion would require another experiment using a different set of stimulus locations. Ideally, vertical and horizontal crossings should be tested independently, distance should be tested within a quadrant without using exactly the same location as the cue, and none of the stimuli should be positioned too near a meridian. Nevertheless, these comparisons generally point to a single consistent result. Neither of the meridian comparisons shows any hint of an increase in response time with meridian crossing. Two of the three distance comparisons show increases with increasing distance, and the third involves a difference in distances that is too small to elicit a measurable effect. Taken together, the results from these comparisons make it unlikely that the response time differences in Experiment 2 could be due to meridian crossings and not to the distance between the image and the stimulus.

Testing for hemispheric differences. This experiment, like the previous one, presents an opportunity to test for hemispheric differences in the use of image representations. To begin with, we performed separate analyses for the image and no-image conditions, using only data from trials in which the stimulus appeared at the cued location, on either the left or right side of the visual field. Surprisingly, in the image condition subjects responded more quickly to the left-hemifield (right-hemisphere) stimuli, $F(1,14) = 4.7$, $p < .05$. This difference probably has little to do with imagery, however, because there was an even larger advantage for the left-hemifield stimuli in the no-image condition, although it did not reach significance, $F(1,14) = 2.4$, $p > .1$. A third analysis combining the shape cue and no-shape cue data for the cued location showed that the overall right-hemisphere advantage was significant, $F(1,14) = 5.1$, $p < .05$, but that it did not differ between the two conditions, $F < 1$. Thus, when the stimulus is at the cued location, this experiment shows no advantage in imagery for either hemisphere, although it does suggest a general (perhaps attentional) advantage for the right hemisphere.

In Experiment 1 the cue always occurred at the center of the display, away from the stimulus locations, and there was at least some evidence for a left-hemisphere advantage in the imagery condition. Perhaps the left-hemisphere imagery advantage only appears when the location must be adjusted in the image. If so, then there should be a left-hemisphere advantage in Experiment 2 for those stimuli at the shortest distance away from the cued location. These stimuli require movement of the image, but they are still located in the same hemifield as the image. Unfortunately, there is no hint of a left-hemisphere imagery advantage in these trials either. In both the image and no-image conditions, responses are faster for the left hemifield (right hemisphere), but the difference is not significant in either, $F(1,14) = 1.8$, $p > .2$ for the no-image condition, $F(1,14) = 3.7$, $p > .07$ for the image condition. When both conditions were combined in a single analysis, the overall right-hemisphere advantage was significant, $F(1,14) = 11.1$, $p < .01$. Although the advantage was slightly larger in the image condition, the difference between the two conditions was not significant, $F < 1$. As with the cued location, there appears to be a general right-hemisphere advantage, but no imagery advantage for either hemisphere. Therefore, Experiments 1 and 2 taken together shed little light on the question of hemispheric advantages in image generation or location adjustment.

Error rates. We subjected the error rates to an ANOVA analogous to that used for the response times, and for each of the important response time effects we examined the corresponding effect in the error rates. In no case did we find any evidence of a speed/accuracy trade-off. As expected, subjects made more errors when the shape was not cued, $F(1,14) = 10.4$, $p < .01$. There were more errors for the two orientations near 180° than for the two orientations near 0°, $F(1,42) = 45.9$, $p < .001$, and this difference was more pronounced when the shape was not cued, $F(1,42) = 16.8$, $p < .001$. The letter R elicited the fewest errors, $F(2,28) = 4.6$, $p < .02$. Normal stimuli tended to produce fewer errors than mirror-reversed, but the trend was not significant, $F(1,14) = 3.7$, $p < .08$. There were no significant error differences due to distance, $F(3,42) = 2.2$, $p > .1$, cue hemifield, $F < 1$, or placement direction, $F(1,14) = 1.1$, $p > .3$.

The error analysis revealed other interesting findings. Error rates were higher for mirror-reversed stimuli than for normal stimuli if the shape was cued, $F(1,14) = 16.7$, $p < .002$. This pattern is consistent with the idea that all stimuli are rotated when the shape is unknown, and a few stimuli, especially those that are mirror-reversed, are rotated when the shape is known. In addition, there were more errors with the no-shape cue than with the shape cue for the letter J, $F(2,28) = 8.2$, $p < .005$, and there were more errors for the number 4 when the stimulus was mirror-reversed than when it is not, $F(2,28) = 5.4$, $p < .02$. Although error rates were generally higher for the two orientations near 180°, there was little difference between orientations with the letter R, $F(6,84) = 2.8$, $p < .02$. There a single additional interaction for which $p < .01$, and eight for which $p < .05$. None of these interactions appeared directly relevant to the questions at hand.

Discussion

Although Experiment 2 uses a procedure that is different from Cooper & Shepard's, it leads to similar conclusions. In both experiments, adjustments of spatial properties require an amount of time proportional to the size of the adjustment, and in both experiments the need for this adjustment time varies depending on whether or not subjects know the shape of the stimulus in advance. The results from both experiments seem to reflect a shape-specific representation in which spatial properties are represented integrally with shape and in which these spatial properties are adjusted gradually.

If there is no linkage between the representation of shape and the representation of orientation or location, then it is difficult to explain why the time necessary to compensate for a change in one of these spatial properties should depend on knowledge of the shape. The data presented in Figure 8 illustrate this point for location adjustments. The pattern in these data is counterintuitive in that the condition with the faster response times also exhibits the larger slope. Overall, subjects were faster when they could prepare an image. When they did, however, they had relatively more trouble with stimuli that were farther from the cued location. Cave & Kosslyn (1989) found a very similar pattern in a size scaling experiment. In that case, responses were generally faster when subjects prepared for the correct shape to appear than when they prepared for the incorrect shape. With the correct shape, however, response time increased more sharply with the ratio between expected and actual size than it did with the incorrect shape. Together these two results suggest that images can generally be used in visual perception to speed certain shape processing tasks, but that in doing so they make visual processing more susceptible to irrelevant differences in spatial properties. For an image representation to be optimally useful in a comparison with a visual stimulus, it must be encoded at the right location. By demonstrating this fact, Experiment 2 underscores once again that the organization of the image representation corresponds in many ways to the organization of the visual input. It also demonstrates a correspondence between mental rotation and other imagery paradigms, such as Farah's (1985) and the image scanning experiments, in which location plays a role.

The data from the no-image condition of Experiment 2 also show an increase in response time with distance, although it is smaller than in the image condition. Presumably this increase reflects differences in the allocation of attention to different locations in the visual field. If for some reason attention were allocated in a more focussed manner in the image condition than the no-image condition, then the entire distance effect might be due to attention, and not the adjustment of an image representation. The plausibility of this explanation, however, depends on the definition of attention. If attention is a general facilitation of processing that applies to any stimulus within a general region of the visual field, then it is difficult to understand why the allocation of this facilitation would vary between the image and no-image conditions. In both conditions, the test stimuli are exactly the same. The task is the same as well, in the sense that in each condition the subject must decide whether a rotated character is mirror-reversed. The only thing that varies between the conditions is the subject's knowledge of the shape. There is no apparent reason why the allocation of this general facilitation would vary with the knowledge of shape, and thus it is more plausible to attribute the distance effect to image adjustment.

Note that Cooper & Shepard's data are subject to the same sort of attentional explanation. Subjects may set themselves for stimuli at a particular orientation, and their ability to select an orientation may vary with their knowledge of the shape. However, there is no reason to expect selection by orientation to differ with knowledge of shape, just as there is no reason to expect selection by location to differ with knowledge of shape. Therefore the attention explanation seems less plausible than the image adjustment explanation for the orientation case, just as it does for the location case.

Additionally, an account based entirely on general attentional differences will have trouble accounting for the data in Figure 9. These data show that the difference between easy and difficult orientations increases with larger distances, suggesting that at the larger distances subjects are more likely to rotate the stimulus after it appears. A general decrease in attentional facilitation should not make rotation any more necessary. However, these data fit well with an image explanation if we assume that image representations "fade" over time, as explained earlier. Because more time is necessary to adjust image location over longer distances, the image is more likely to fade, forcing the subject to rotate the stimulus when it appears. Therefore, these data support an explanation based on image location adjustment over one based on a change in general attentional facilitation.

On the other hand, attention might be a more specific sort of facilitation. It is conceivable that subjects can set themselves to expect a particular shape at a particular location, and that when they do they respond more quickly to this shape at this location than to any other shape or to the same shape at any other location. However, there seems to be little difference between setting oneself to see a particular shape at a particular location and imaging that shape at that location. This sort of attention seems to have much in common with visual imagery, and if the distance effect is due to this sort of attention, then it might very well be considered the result of imagery.

Rate of location adjustment. Experiment 1 demonstrated that if location adjustments in image representations take any time at all, it is a very small amount of time, and thus not easy to measure. Nevertheless, Experiment 2 succeeded in measuring that adjustment time, and it is indeed fast enough to account for the similarity between the results of Experiment 1 and those of Cooper & Shepard. From the slope displayed in Figure 8, we can conclude that subjects in Experiment 1 probably required an extra 40 msec or so to respond to each stimulus in the shape cue condition because they did not know where it would appear. Of course, part of this extra time may be due to the allocation of attention rather than to image location adjustment. From these results, we conclude that the representations used in mental rotation are *not* location-independent, but they are the next best thing. The representation is coded for a specific location, but that represented location can be adjusted quickly and easily when necessary.

The results from Experiment 2 can be compared specifically with results from image scanning experiments by comparing the rate at which location is adjusted. To determine the rate at which images "move" in this experiment, we can use the slope for the image condition depicted in Figure 8. However, determining the adjustment rate is complicated in this experiment. The image and the focus of visual attention will be at the same location, and thus part of the slope for the image condition might be due to attentional factors. The no-image condition demonstrates that responses are slower when the stimulus is at an unexpected location. If the extra processing necessary for unexpected locations can be done concurrently with the movement of the image, then the entire slope in the image condition should reflect location adjustment. If instead, the extra processing must be done before or after the location adjustment, then the location adjustment slope is only the difference between the slopes in the image and no-image conditions. Of course, if there is only a partial overlap between the extra processing and the image overlap, then the image adjustment slope will be somewhere between these two extremes.

If we cannot be certain of the image adjustment rate from the data for Experiment 2, we can at least determine upper and lower bounds. Assuming the slope in the image condition reflects only image adjustment time, then images in this experiment "move" at about 6.3 msec per degree of visual angle. If attention plays as big a role in the slope of the no-image condition as it does in the image condition, then the image adjustment rate is about half that amount. The maximum rate of 6.3 msec/degree is faster than the 17 msec/degree found by Kosslyn (1978) when he specifically instructed subjects to scan across images, and is also faster than the 19.8 msec/degree found by Finke & Pinker (1982) in their dots task. This difference in rates does not necessarily mean that different types of location adjustments are used in these different experiments. In the experiments by Kosslyn and by Finke & Pinker, subjects must maintain images of multiple distinct visual objects, and especially in the Finke & Pinker experiment they must be careful to accurately preserve the distances between objects. In our experiment, there is no spatial configuration of different objects to maintain. Because this task is simpler, subjects may be able to adjust location more rapidly.

The results from Experiment 2 demonstrate some of the similarities between the representation of orientation and location in visual images, and in doing so they shed new light on the nature of image representations in general. Location information, like orientation information, is encoded integrally with shape information. As with location, the adjustment of represented location is accomplished either continuously or in small steps. Because objects do not generally appear at a single standard location, however, location adjustments may not be necessary as often as orientation adjustments. In many circumstances, location adjustments may also be unnecessary because of eye movements. If a stimulus to be compared with an image appears at an unexpected orientation, the subject must either rotate the image or the stimulus representation, or else tilt the head. In most situations, however, if a stimulus appears at an unexpected location, subjects will first saccade to it to gain maximum acuity. If the image is located at the fovea, then it may not be necessary to adjust the image location. This possibility raises questions about the frame of reference used in image representations, which Experiment 3 is designed to address.

Experiment 3

If location is in fact encoded in these mental representations, then we can ask what sort of coordinate frame is used. The visual input is necessarily organized according to location on the retina. In order to navigate through space and manipulate physical objects, some stage of visual processing must include an integration of information from different fixations using a single (spatiotopic) frame of reference. Therefore, we can ask whether location is encoded retinotopically or spatiotopically in these image representations.

Up to this point we have emphasized the implications of these experiments for the nature of visual image representations. However, the subjects in these experiments were not instructed to use imagery; they were simply told to decide whether or not the shapes were mirror-reversed. Therefore, the task used here is in some sense a perceptual task as well as an imagery task, and understanding more about how this task is done will lead to a better understanding of at least one aspect of shape discrimination. By determining the coordinate frame used in these mental representations, we will gain another piece of evidence that can be helpful in ascertaining the level at which these representations are used in regular visual processing. Of course, in order for this evidence to be useful, we must have some idea of where in the stream of visual processing the retinal coordinates are converted to a more useful reference frame.

There are good reasons for expecting the coordinate shift to occur early in visual processing, and Feldman (1985a) uses this strategy in his Four Frames Model. In this model, visual information in the retinotopic frame is transferred to a part of the stable feature frame. The location within the stable feature frame for each fixation is determined by eye position. Thus multiple fixations can be integrated into a single, complete representation. The stable feature frame is still spatially organized: Shape properties are still an integral part of the representation of each shape. Instead of coding location in terms of retinal position, however, the stable feature frame codes location in relation to head position[2]. Virtually all high level visual processing is then based on the stable feature frame, and not the retinotopic frame.

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[2] Once coordinates are coded in a head-centered reference frame, another transform is necessary to produce coordinates coded in a reference frame based on the environment. This transform must take into account head and body position relative to the environment. For the

Feldman (1985a, 1985b) cites a number of reasons for implementing an early coordinate shift in his model. First, the early shift makes it easy to integrate information across fixations. Even when the viewer is too close to an object to see it all in a single fixation, it is possible to assemble all the parts together into a single coherent representation. He also feels that the stable feature frame can serve as a necessary "substrate" for our subjective experience of a visual world that is unified across fixations. He also states that it can be used for imagery, although he does not elaborate on the disadvantages of implementing imagery in the retinotopic rather than the spatiotopic frame. Finally, he lists perceptual experiments that are consistent with the presence of the stable feature frame. Among these experiments was one by Davidson, Fox, & Dick (1973). They presented subjects with an array of letters, had the subjects move their eyes, and then presented a mask at one of the letter locations. When the subjects were asked to report the location of the mask, they usually reported its correct spatiotopic location.

If the coordinate shift occurs as early in visual processing as Feldman claims, then image representations are almost certainly not coded retinotopically. In spite of his evidence, however, there are other reasons to believe that the coordinate shift occurs later in processing; perhaps *after* stimuli are compared with these image representations. One reason arises from the Davidson, Fox, & Dick's data. Although subject reports linked the mask with its spatiotopic location, it interfered with the letter at the same retinotopic location. Using a

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present purposes, we will ignore the distinction between head-centered and spatiotopic reference frames. The question we are pursuing concerns when coordinates are transformed from a retinotopic frame to a more useful reference frame, regardless of whether the new frame is head-centered or spatiotopic. In all the experiments described here, there were no head movements, and thus a transform from retinotopic to head-centered coordinates would be indistinguishable from a transform from retinotopic directly to spatiotopic coordinates.

similar methodology, Irwin, Brown, & Sun (1988) also found that mask interference depended on retinotopic location. They then tested the integration of information across saccades more carefully by replacing the mask with a small bar, and asking subjects to report the letter that occurred at the same location as the bar. As long as the delay between the letter array and the bar was short, subjects reported the letter at the same retinotopic location more often than the letter at the same spatiotopic location, even though in many trials they could also correctly report the spatiotopic location of the bar. With a longer delay, they more often reported the letter at the same spatiotopic location, but they also reported a different visual experience, with the stimuli before and after fixation no longer fused together as they were with the shorter delay. In their final experiment, Irwin, Brown, & Sun used a task that required the fusion of two dot patterns into a single form. Performance on this task was better when the two patterns occupied the same retinotopic location than when they occupied the same spatiotopic location.

Irwin, Brown, & Sun's results indicate that, at least over short time intervals, information across saccades is integrated within a retinotopic coordinate frame, rather than within a spatiotopic or head-centered system as it would be in the stable feature frame. They conclude that when the delay is longer and the information from different fixations is integrated spatiotopically, this integration is not done within the early stages of visual processing that are the basis for visual persistence. More recently, Irwin, Zacks, & Brown (1989) have collected additional evidence by testing for a spatial-frequency-specific priming effect. Normally, subjects are less accurate at detecting a grating stimulus when another grating of the same spatial frequency has just appeared at the same location. When Irwin, Zacks, & Brown's subjects moved their eyes between the cue and the test gratings, there was no decrease in performance, even though the two gratings occupied the same spatiotopic location.

More serious doubts about the early coordinate shift arise from neuroanatomical and neurophysiological studies of the visual system. Although these studies have discovered numerous brain regions devoted to different aspects of visual processing, the receptive fields of the cells in almost all of these regions appear to be retinotopically organized. One partial exception is in posterior parietal cortex, where Andersen, Essick, & Siegel (1985) found individual units that responded to stimuli at a particular retinotopic location, but only for particular eye positions. These units could be part of a distributed representation that encodes location in head-centered coordinates (Zipser & Andersen, 1988). This area of the brain, however, appears to be devoted to the processing of location, while working in conjunction with another system in the temporal lobes that processes identity (Ungerleider & Mishkin, 1982). Lesions in this area interfere with monkeys' ability to detect the location of a stimulus, but not to identify visual patterns. Thus, the role of posterior parietal cortex in visual processing is much later than Feldman's stable feature frame. When Kosslyn, Flynn, Amsterdam, & Wang (in press) constructed a model of higher-level visual processing, the accumulated evidence from neuroanatomy and neurophysiology led them to omit an early spatiotopic frame. In their model the spatiotopic transform occurs in the location subsystem, after location information has been factored apart from shape information. The shape information that is matched against memory representations and categorized by the identity subsystem has not been transformed into spatiotopic coordinates.

Experiment 3 is designed to test whether the representations used in mental rotation are coded retinotopically or spatiotopically. The answer to this question is important in determining how these representations are used in visual processing. It could also have general implications for the coding of location in all types of visual processing, and for the way that information is integrated across fixations. If retinotopic representations are used in mental rotation, then a coordinate shift is unlikely to occur early in visual processing.

The general strategy in Experiment 3 is to measure the response time advantage that occurs when the image occupies the stimulus location, as was demonstrated in Experiment 2. By introducing a saccade in between the image cue and the test stimulus, we can measure whether this advantage is associated with the retinotopic or the spatiotopic location. Given that image location can be adjusted so quickly, measuring the location advantage will be difficult in this experiment. The difficulty will be confounded somewhat by the layout of the display, which requires that the maximum distance between cue and test stimulus be smaller than in Experiment 2.

Method

Subjects. As in Experiment 2, we used a pupil tracker in this experiment to monitor eye movements. Most subjects required practice before they could respond to a stimulus in the periphery without moving their eyes, and some were unable to finish the experiment or chose to quit early. Once the data for a subject were collected, all values that were more than three standard deviations from the mean for that subject were removed. By removing outlying data points in this fashion, we hoped to eliminate extraordinarily long response times that can occur when subjects lose concentration or miss a briefly-presented stimulus. After the outliers were removed, a few subjects did not have data for every combination of conditions. In all, a total of 75 subjects completed the experiment with a full set of data, and another 44 subjects did not. All subjects were from the

M. I. T. Department of Brain and Cognitive Sciences subject pool, and all were paid for their time, whether or not they completed the experiment. Most were M. I. T. undergraduates, and their vision was normal or corrected to normal. These subjects did not participate in the earlier experiments.

Apparatus. The computer, display, pupil tracker, and video camera used in Experiment 2 were all used in this experiment.

Stimuli. The test stimuli were the same three characters, either normal or mirror-reversed, displayed at the same four orientations, 45°, 135°, 225°, and 315°. The two types of cues were also the same: Each shape cue was a normal character oriented appropriately, and each no-shape cue was a rectangle with a small arrow indicating the top, also oriented appropriately.

In this experiment, there were three possible locations at which the cue and test stimulus could appear, as shown in Figure 12: One at the center, one at the far left, and one at the far right. The fixation cross could appear at one of two locations: Either between the center and left stimulus locations, or between the center and right locations. A cue or test stimulus could only occur in one of the two locations next to the current fixation cross. The distance between each fixation cross and each of the two neighboring stimulus positions was 4.8 cm (5.5°). With this arrangement, a test stimulus occurring to the right of the left fixation cross would occupy the same location on the screen as a stimulus to the left of the right fixation cross.

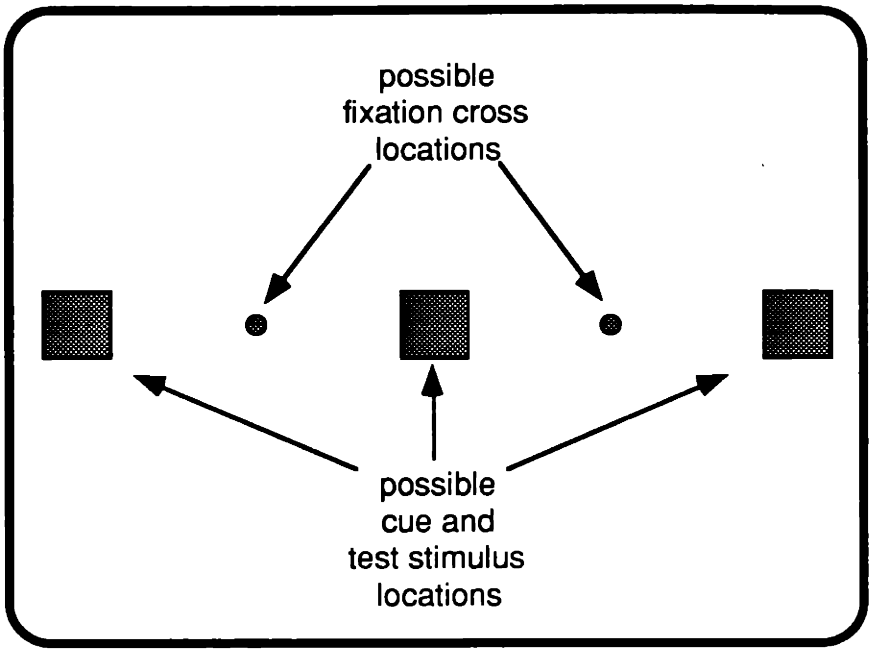


Figure 12: The two locations at which a fixation cross could appear, and the three locations at which a cue or test stimulus could appear.

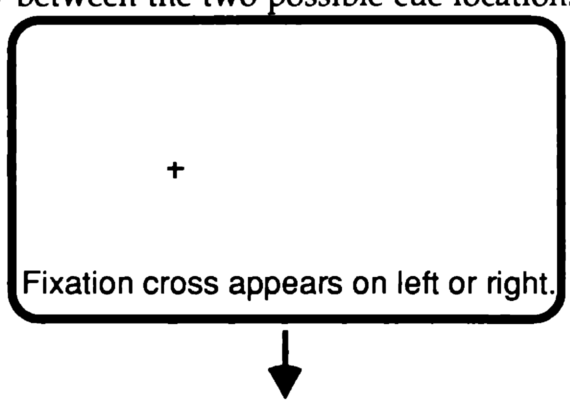
Suppose that a subject fixates on the left fixation cross and then views a cue to the right of the fixation cross (in the center of the screen). The subject then saccades to the right fixation cross. If a test stimulus now appears to the left of the new fixation cross, it will be in the same spatiotopic location as the cue. If it instead appears to the right of the fixation cross, it will be in the same retinotopic location as the cue. In this experiment, the cue and test stimulus always appeared at one of the two locations next to the current fixation cross. Therefore, the distance of the cue and test stimulus from the fovea was always constant.

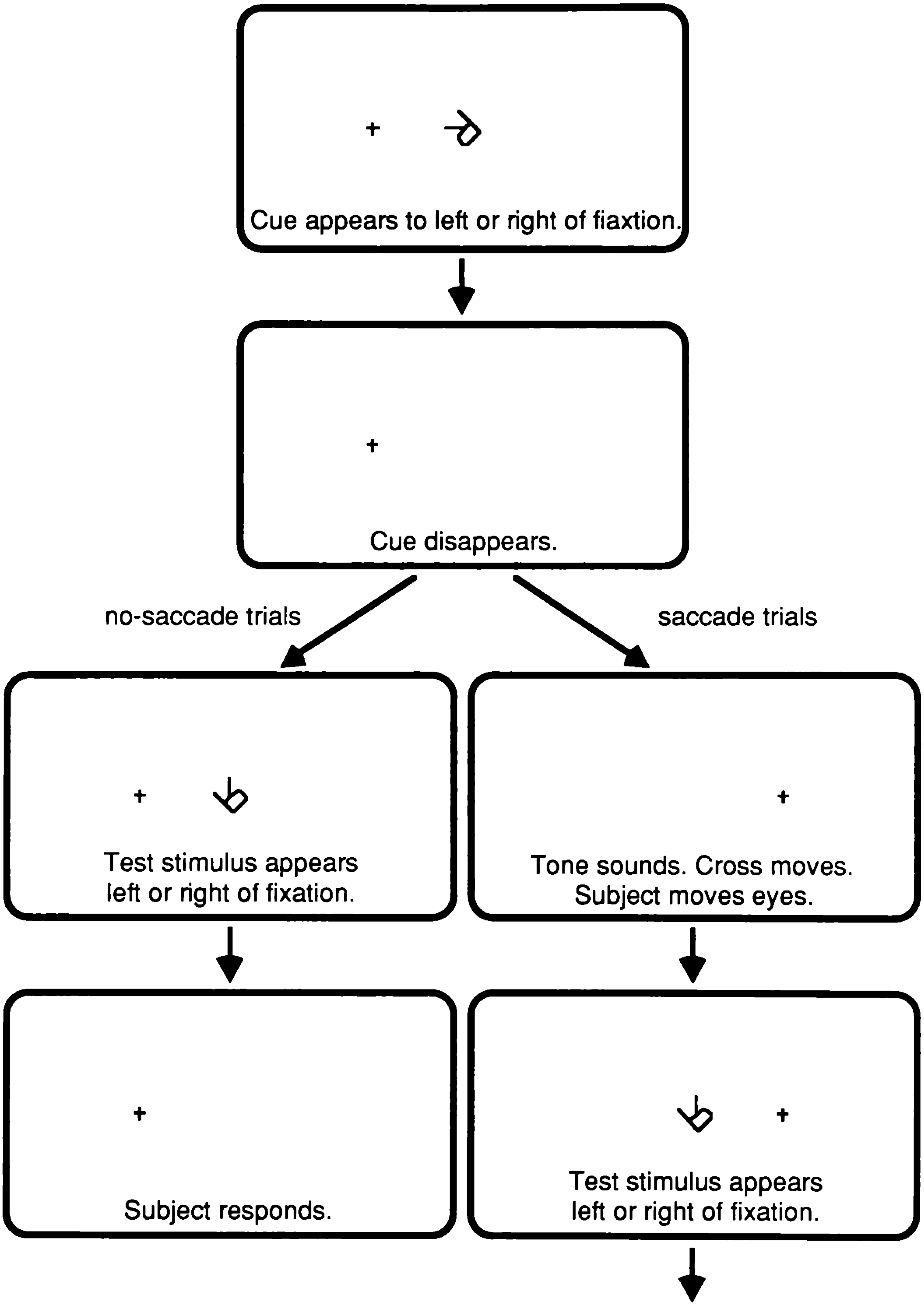
Procedure. As in the previous experiments, the subject was seated in front of the CRT in a dimly lit room. A chin rest and forehead restraint were used to maintain a constant viewing distance and prevent head movements. The subject was instructed to keep one hand on each of the response keys.

Because the eye tracker was used to monitor saccades in this experiment, a short calibration procedure was necessary for each subject prior to testing.

During this procedure, the eye tracker monitored eye position while the subject performed a simple visual task that required saccades back and forth between two points on the screen. The calibration program calculated the median difference between the pupil locations before and after each saccade, and this value was used in the regular experiment to predict the correct eye position after a saccade was cued. This calibration procedure was repeated at the beginning of each testing session.

Figure 13 illustrates the various steps of the experiment itself. Each trial began with the appearance of a fixation cross at one of the two possible locations. The subject was instructed to fixate on the cross when it appeared. After the cross had been visible for 1500 msec, the eye position was recorded and the cue appeared, either to the left or the right of the fixation cross. The cue was present for 700 msec, and then disappeared, leaving only the fixation cross for another 1500 msec. The subject was instructed to remain fixated on the cross during this entire time, and if the computer detected a substantial eye movement the trial was aborted, as in Experiment 2. Note that once the fixation cross appeared, the cue was equally likely to appear 4.8 cm to the left or to the right of the cross. Therefore the subject's best strategy was to follow the instructions and to fixate on the cross, half way between the two possible cue locations.




Cue appears to left or right of fiaxtion.
Cue disappears.
no-saccade trials
saccade trials
Test stimulus appears
left or right of fixation.
Tone sounds. Cross moves.
Subject moves eyes.
Subject responds.
Test stimulus appears
left or right of fixation.

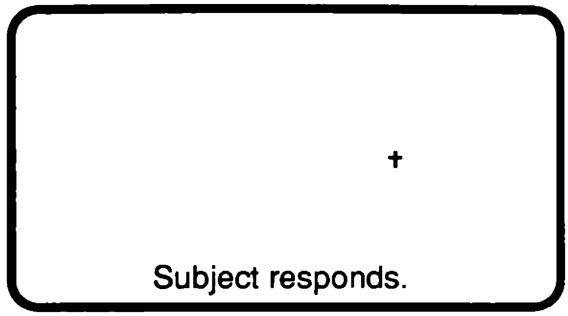


Figure 13: The sequence of events for no-saccade trials and saccade trials in Experiment 3.

The next step in the procedure varied between the two different types of trial. In the no-saccade trials, the test stimulus was presented for 120 msec, either at the cued location on one side of the fixation cross or at the uncued location on the other side. The subject then responded as in the previous experiments. In the saccade trials, however, a tone sounded, and the fixation cross moved to the other fixation location on the other side of the display. This was the subject's cue to shift fixation to the new location. At this point, the computer no longer compared the eye position to the standard eye position measured at the beginning of the trial. Instead, it calculated a new standard position by adjusting the old position according to the values from the calibration procedure. It then began comparing the eye position against the new standard, using the same threshold as before. If the eye position did not come within the threshold range of the new standard within 2000 msec, the trial was aborted. Once the eye position came within the threshold range, it was compared for an two additional pupil tracker cycles (approximately an additional 34 msec) to ensure that the eye was no longer moving.

After this third eye position comparison, the current eye position was taken as the new standard for the rest of the trial. The test stimulus then appeared on either side of the new fixation cross, and the subject responded appropriately. The test stimulus was equally likely to occur 4.8 cm to the left or right of the new fixation cross. Thus, as before, once the new fixation cross appeared, the subject's best strategy is to follow the instructions and to fixate on the cross, half way between the two possible stimulus locations.

After an incorrect response, the screen flashed blue and a long tone sounded. In both types of trials, eye movements were monitored until the subject responded. If an uncued saccade occurred at any stage of the trial, the screen flashed red and a long tone sounded. Using the same procedure as in Experiment 1, trials with incorrect responses or incorrect eye movements were repeated after each block of 96 trials, and this process continued until all trials in the block had been completed correctly. Subjects were given an opportunity for a break after every 20 trials.

In this experiment, half the trials were saccade trials and half were not. Within each type, half were shape cue trials and half were not. The fixation could be either to the left or right of center, and the cue could be to the left or right of fixation. The test stimulus could be at the cued or uncued location, it could be one of three shapes, it could be at one of four orientations, and it could be either normal or mirror-reversed. All the different combinations produce a total of 768 trials for each subject. A different random order was generated for each. Most of the 75 subjects who completed the entire set of trials required four or five sessions, each lasting about an hour.

Given that subjects can adjust represented location in images so quickly, they might be able to produce either retinotopic or spatiotopic results by "moving" their images as they move their eyes. Assuming for the moment that images are coded spatiotopically, if the subject believes that the image should always be in the same retinotopic location as the cue, then after a saccade the subject could shift the image to the spatiotopic location that now corresponds to the retinotopic location of the cue. Likewise, if images are coded retinotopically, subjects could move the image to the correct spatiotopic location after the saccade. To investigate this possibility, we randomly split the 75 subjects into three groups of 25 each, and gave each group slightly different instructions. All three groups were instructed to prepare for the test stimulus at the location occupied by the cue. Subjects in the retinotopic group were told that on saccade trials, they should expect the test stimulus at the same location relative to the fixation cross as the cue. Those in the spatiotopic group were told to expect the test stimulus at the same location on the screen as the cue. Those in the neutral group received no instructions either way. In all three trials, there was an equal number of trials at the cued and the uncued locations. As in the previous experiments, none of the instructions mentioned anything about imagery. If subjects are able to adjust image location before the stimulus appears, then the location for which subjects respond more quickly should vary with the instructions they receive.

Results

To determine whether the image representations used in this task are retinotopic or spatiotopic, we must look at those trials in which the test stimulus could occur at either the same retinotopic location or the same spatiotopic location as the cue. Therefore, we discarded data from all trials in which the cue appeared at the far left or right of the screen, because after a saccade the test stimulus could never occur at the same spatiotopic location in these trials. These trials were included in the experiment to ensure that subjects fixated at the appropriate location.

Response times. The trials without saccades serve as a control condition to test whether the location-specificity found in Experiment 2 can be measured in the current experiment. These trials demonstrated that subjects responded more quickly in this task when the test stimulus occurred at the same location as the cue. The response time data for trials with and without saccades were submitted to separate ANOVAs, with cue, orientation, location, handedness, shape (R, J, or 4), and type of instructions as factors. Subjects made incorrect responses on 2% of the trials, and these trials were excluded from the analyses. Because the results from Experiments 1 and 2 indicated that any retinotopic or spatiotopic advantage would be very subtle, we wanted to ensure that any small effects were not obscured by long response times from trials in which subjects lost their concentration. Therefore we excluded trials with response time values more than three standard deviations from the subject's mean. (On the average, only 7 of the 768 correct-response trials for each subject were excluded). In the results described below, the values F_f and p_f are from the analysis of trials in which the eyes remained fixed, and the values F_s and p_s are from the analysis of trials in which there was a saccade.

In both saccade and no-saccade trials, the results indicated that subjects were using images when possible, as they had in the previous experiments. Responses were faster when subjects knew the shape beforehand, $F_f(1,72) = 170.9$, $p_f < .001$, $F_s(1,72) = 167.4$, $p_s < .001$. Contrasts indicated that they were also faster for the two orientations near 0° than for the two near 180°, $F_f(1,216) = 761.2$, $p_f < .001$, $F_s(1,216) = 712.7$, $p_s < .001$, and that the advantage for the easier orientations was greater when subjects knew the shape, $F_f(1,216) = 48.0$, $p_f < .001$, $F_s(1,216) = 30.4$, $p_s < .001$, suggesting once again that knowledge of the shape allowed subjects to form images. As before, responses were slower when stimuli were mirror-reversed than when they were normal, $F_f(1,72) = 128.9$, $p_f < .001$, $F_s(1,72) = 92.5$, $p_s < .001$, and as before they were generally faster for R and slower for 4,

$F_f(2,144) = 14.9$, $p_f < .001$, $F_s(2,144) = 8.0$, $p_s < .01$. The three different instruction sets had no significant overall effect on response times, $F_f < 1$, $F_s < 1$.

When the eyes remained fixed, subjects responded more quickly when the test stimulus occurred at the same location as the cue, $F_f(1,72) = 74.4$, $p_f < .001$. This advantage is no doubt due at least partly to attentional factors, and therefore it is important to test whether this location advantage is stronger in the image (shape cue) than in the no-image (no-shape cue) condition. In fact, it was stronger in the image condition, $F_f(1,72) = 33.7$, $p_f < .001$, as can be seen in Figure 14, confirming the finding from Experiment 2 that image representations include information about location.

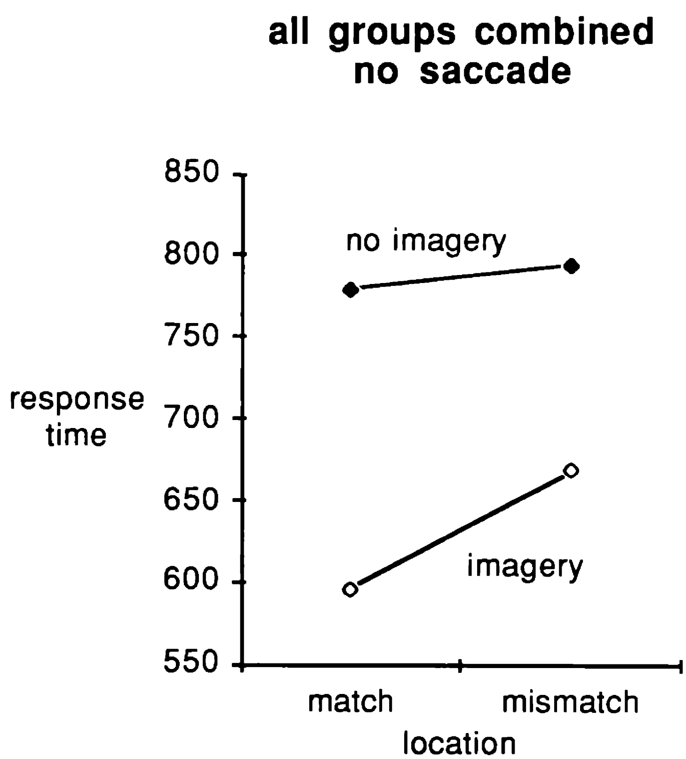


Figure 14: Mean response time for no-saccade trials when test stimulus location matched the cued location and when it did not. Responses were faster when the stimulus appeared at the cued location, but the advantage was much greater in the image condition.

The results from the no saccade trials confirm that this particular task can be used to measure the advantage that comes from having an image in the right location. Thus we should be able to use the data from the saccade trials to answer whether location information in images is encoded retinotopically or spatiotopically. Overall, subjects responded faster to stimuli in the same retinotopic location as the cue than to those in the same spatiotopic location as the cue, $F_S(1,72) = 7.7$, $p_S < .01$. More importantly, the retinotopic advantage was stronger in the image condition than in the no image condition, $F_S(1.72) = 5.9$, $p_S < .02$, as is shown in Figure 15. From this difference we conclude that image representations are encoded in a retinotopic coordinate system.

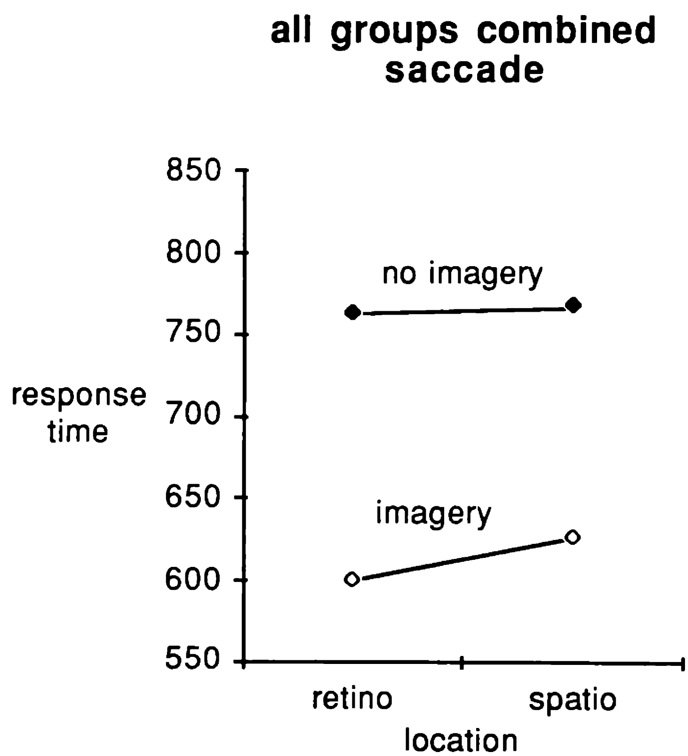


Figure 15: Mean response time for saccade trials when test stimulus location matches the retinotopic location and when it matches the spatiotopic location. Responses were faster when the stimulus

appeared at the retinotopic location, and the advantage was much greater in the image condition.

This experiment yielded a number of other results that are not directly relevant to the question of retinotopic representation, but may be interesting nonetheless. These effects tended to appear more often in the trials without eye movements. Forcing the subject to make a saccade between the cue and the test stimulus probably produces a certain amount of interference that may obscure some effects. This interference could explain why some effects reached significance only in the trials without saccades.

As in Experiment 2, this analysis suggests that even when subjects know the shape, they occasionally rotate the stimulus before responding, especially if it is mirror-reversed. With no saccade, the gap between normal and mirror-reversed response times was larger when the shape was known than when it was not, $F_f(1,72) = 19.8$, $p_f < .001$. Additionally, when the shape was known, response time differences between easy and difficult orientations were larger for mirror-reversed than for normal stimuli; when the shape was not known, orientation differences actually seemed to be *smaller* for the mirror-reversed stimuli than for the normals, $F_f(3,216) = 7.0$, $p_f < .001$. The same was true for the saccade trials, $F_s(3,216) = 6.7$, $p_s < .001$.

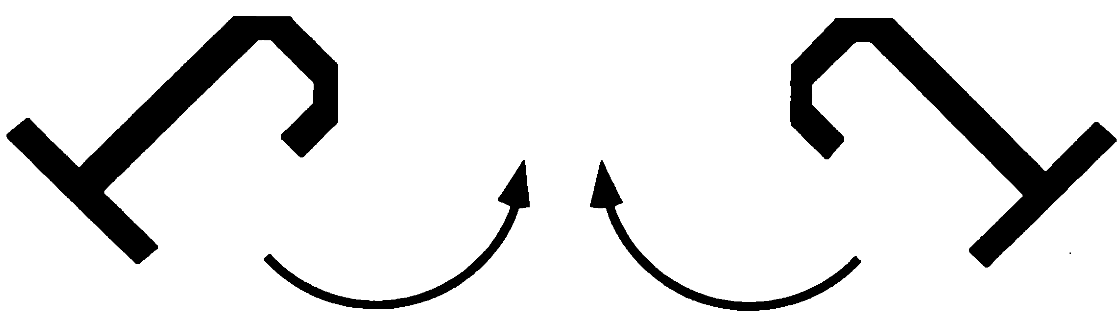


Figure 16: The data from the no-saccade condition suggest that subjects sometimes rotate in the direction of the top front of the character, even if the shorter path is in the other direction.

In addition, with or without saccades there are large differences in response times for the two difficult orientations, depending on the handedness of the stimulus, $F_f(3,216) = 9.2$, $p_f < .001$, $F_s(3,216) = 4.8$, $p_s < .01$. These interactions, along with the ones just described, reflect another effect that was not anticipated. The data suggest that subjects tend to rotate in the direction of the top front of the letter, even if rotating in this direction requires more time than rotating in the other direction. This method of rotation is illustrated in Figure 16. Thus, if a mirror-reversed stimulus is oriented at 225°, at least some of the subjects apparently rotated it counter-clockwise on at least some of the trials, even though they could save 90° of rotation by rotating it clockwise. Similarly, normal stimuli at 135° tended to rotate clockwise, even though the path of rotation would be shorter for a counterclockwise rotation. The evidence for this pattern is presented in Figure 17.

In the no image condition, response times for normal stimuli at 135° were greater than times for those at 225°, whereas the opposite pattern held for the mirror-reversed stimuli. This rotation towards the front seems most likely to occur with the shape J, $F_f(6,432) = 5.0$, $p_f < .001$, $F_s(6,432) = 2.8$, $p_s < .02$. The same pattern of rotating towards the front appeared in a weaker form in the image condition, as would be expected if subjects occasionally rotated stimuli in this condition. A hint of the same pattern also appeared in the data from Experiment 2, although it was less clean and not significant. An alternative explanation is that rotating a character towards the top back is more difficult than rotating it towards the top front.

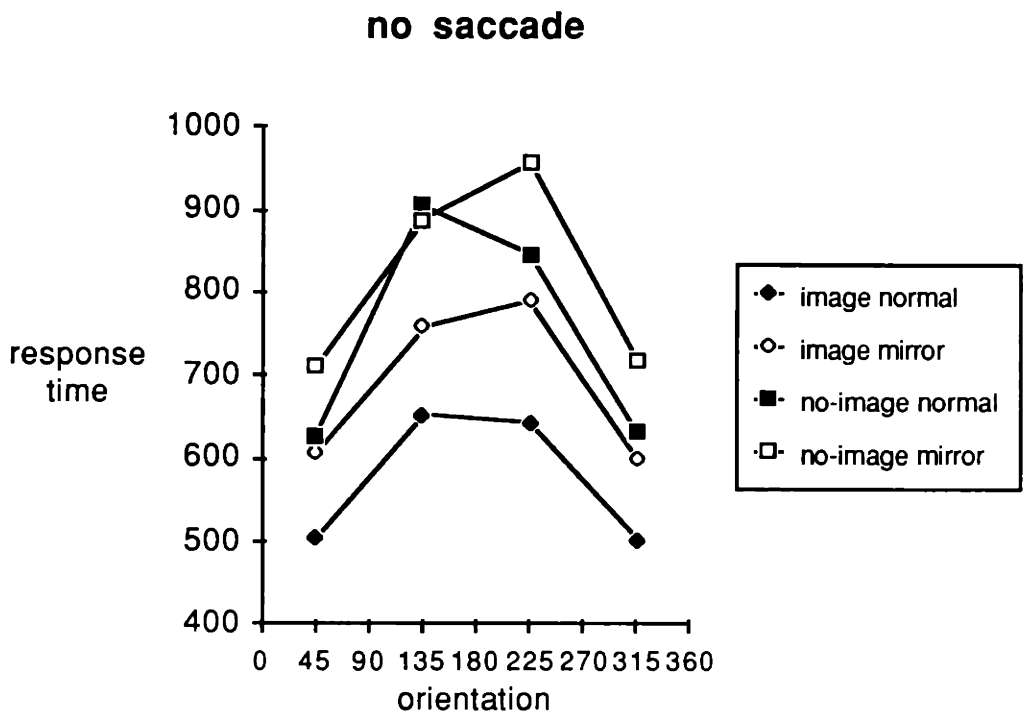


Figure 17: Data illustrating the tendency to rotate towards the top front of the character. For normal stimuli in the no-image condition, response time was elevated for 135°. For mirror-reversed stimuli, response time was higher for 225°.

Responses to stimuli in the cued and uncued locations in the trials without saccades provided more evidence that subjects occasionally rotated stimuli in the image condition. When the shape was cued, there was a greater response time difference between easy and difficult orientations for stimuli that appeared at the uncued location than for those that appeared at the cued location; without the shape cue, the orientation difference was not greater for the uncued location, and may actually have been less, $F_f(3.216) = 4.3$, $p_f < .01$. This pattern suggests that when subjects know the shape, they are more likely to rotate the stimulus if it occurs at the uncued location. This is the same sort of pattern seen in Figure 9 in Experiment 2. If the stimulus is at the uncued location, then the image that was prepared beforehand must be moved to the new location before it can be used, and thus subjects are more likely to abandon the image and rotate the stimulus.

Also in the no-saccade trials, subjects responded slowly to the shape J when it appeared at one of the two difficult orientations (135° and 225°); however, their responses were faster for the 135° J's if they knew the shape beforehand, $F_f(6{,}432) = 2.9$, $p_f < .01$. There were three other significant interactions ($p < .05$) in the no-saccade ANOVA, and three in the saccade ANOVA. None reached the significance level of the effects reported here ($p > .01$ in all cases), and none appeared directly relevant to the questions at hand.

Spatiotopic advantage. The main analysis tested whether there was an advantage for the retinotopic location over the spatiotopic location, but it did not test whether the spatiotopic location had any advantage over other locations that did not match either the retinotopic or spatiotopic cue location. We tested for this advantage with another analysis that included two sets of saccade trials: those in which the test stimulus appeared at the spatiotopic cue location, and those in which the stimulus did not appear at the same retinotopic or spatiotopic location as the cue. In this second set of trials, the cue appeared at one edge of the display and the test stimulus appeared on the other. The other factors in this analysis (cue, orientation, handedness, shape, and type of instructions) were the same used in the main analysis.

As before, the important question is whether there is an advantage for the spatiotopic location in the image condition that does not exist in the no-image condition. The interaction shows a trend in that direction that is not quite significant, $F(1{,}66) = 3.9$, $p < .06$. Response times were no faster for the spatiotopic location than for the nonspatiotopic location in the no-image condition, but they were 17 msec faster in the image condition. If there is in fact an advantage for stimuli at the spatiotopic location over those at other locations, it may be because some subjects occasionally move their image to the spatiotopic location when they move their eyes. Another possibility is that subjects sometimes lose their image during the saccade and try to reconstruct it. If so, they are probably at least as likely to place it at the spatiotopic location as at the retinotopic location. If subjects do occasionally move an image to the spatiotopic location, we might expect that they would be more likely to do so when they are instructed to expect the stimulus at the spatiotopic location. However, the differences in the spatiotopic image advantage across the different instruction groups were not significant, $F < 1$.

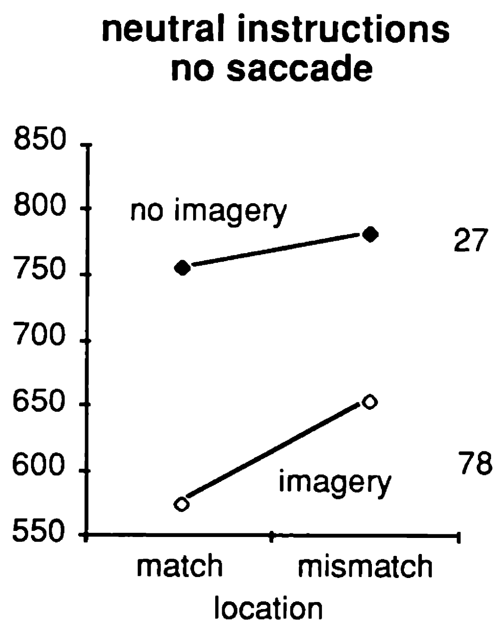
Error rates. To test for possible speed/accuracy trade-offs, we performed two analogous ANOVAs using the error rates from the no-saccade trials and from the saccade trials, and in each we examined the main effects and interactions that corresponded to those we examined in the response time analyses. In both analyses, subjects made more errors when they did not know the shape, $F_f(1,72) = 13.6$, $p_f < .001$, $F_s(1,72) = 28.6$, $p_s < .001$. They also made more errors for the two orientations near 180°, $F_f(1,216) = 103.7$, $p_f < .001$, $F_s(1,216) = 109.0$, $p_s < .001$. In the saccade trials, they made relatively more errors for orientations near 180° when they did not know the shape, $F_s(3,216) = 6.3$, $p_s < .025$, as would be expected if they used images when they knew the shape. This effect did not reach significance in the no-saccade trials, $F_f < 1$, although the trend was in the right direction. In the saccade trials, the letter R elicited fewer errors than the other two shapes, $F_s(2,144) = 4.8$, $p_s < .02$, although this effect was not significant in the no-saccade trials, $F_f < 1$. In neither the saccade or the no-saccade trials was there any significant difference in error rates due to handedness, $F_f(1,72) = 1.3$, $p_f < .2$, $F_s < 1$, or instructions, $F_f(2,72) = 1.2$, $p_f > .3$, $F_s < 1$.

There was no significant overall difference between the error rates for stimuli at cued and uncued locations, either with or without saccades, $F_f < 1$, $F_s(1,72) = 1.1$, $p_s > .25$. In the no-saccade trials, however, there was an advantage for the cued location in the image condition that was balanced by an advantage for the *uncued* location in the no-image condition, $F_f(1,72) = 6.4$, $p_f < .02$. Performance in the no-image condition was only slightly better at the uncued location than at the cued location, but it raises the possibility that the faster response times at the cued location might be due in part to a speed/accuracy trade-off rather than to the allocation of visual attention, as suggested earlier. Whatever the explanation for the no-image data, there is no hint of a speed/accuracy trade-off in the image condition: When subjects knew the shape beforehand, they responded faster to stimuli at the cued location *and* they made fewer errors. Thus there is no reason to doubt the conclusion that performance improves when the stimulus appears at the same location as the visual image. In the saccade trials, there was no interaction between cue and retinotopic/spatiotopic location, $F(1,72) = 1.4$, $p > .2$, and thus there is no reason to believe that the retinotopic advantage in the response times is due to a speed/accuracy trade-off.

These two analyses produced some other results as well. As with the response time data, there were fewer significant effects in the saccade trials than in the no-saccade trials, probably because of the disruption associated with a saccade. In the saccade trials, there were a relatively large number of errors for the numeral 4 at 135° and for the letter J at 225°, $F_s(6,432) = 2.7$, $p_s < .02$. A similar pattern appeared in the no-saccade trials, but only for mirror-reversed stimuli, $F_f(6,432) = 2.1$, $p_f < .05$. These two shapes at these two orientations appear similar, and subjects probably confused them on some trials. In both analyses, the advantage for normal stimuli over mirror-reversed was strong in the image condition, but there actually appeared to be a disadvantage for the normal stimuli in the no-image condition, $F_f(1,72) = 22.1$, $p_f < .001$, $F_s(1,72) = 14.5$, $p_s < .001$. This somewhat surprising pattern was more clearly demonstrated in the no-saccade trials, in which the effects of cue generally depended on which of the three shapes was presented, $F_f(2,144) = 4.0$, $p_f < .025$. Specifically, all of the normal stimuli showed an advantage when the shape was cued, but with the mirror-reversed stimuli the shape cue produced an advantage for the letter R, almost no advantage for the letter J, and an apparent *disadvantage* for the numeral 4, $F_f(2,144) = 3.5$, $p_f < .04$.

The difference in error rates between stimuli at easy and difficult orientations varied across different types of stimuli in the no-saccade trials, suggesting once again that subjects' rotation strategies varied across conditions. In the image condition, the difficult orientations produced relatively more errors when the stimulus was mirror-reversed than when it was not, whereas there was no such difference in orientation gaps between normal and mirror-reversed stimuli in the no-image condition, $F_f(3,216) = 5.1$, $p_f < .005$. If anything, the orientation gap in the no-image condition was larger for normal than for mirror-reversed stimuli. In general, the orientation gap was fairly large in the no-image condition; in the image condition, the gap was small for normal stimuli, larger for mirror-reversed stimuli, and larger still for mirror-reversed stimuli at the uncued location, $F_f(3,216) = 3.2$, $p_f < .025$. If we assume that subjects are more likely to make errors when they are forced to rotate the stimulus, then this pattern is generally consistent with the idea that subjects usually (or always) rotate in the no-image condition, but only rotate occasionally in the image condition, generally when the stimulus differs from the image in handedness or location. There were no other significant interactions in either the saccade or the no-saccade analysis ($p < .05$ in all cases).

Varying the instructions. For both the saccade and the no-saccade data, separate response time ANOVAs were computed for the three types of instructions used. Each instruction group included 25 of the 75 subjects who participated in this experiment. Our purpose in manipulating the instructions was to determine whether subjects had the option of either moving their images with their eyes or attaching them to a point in space. Therefore our main concern is with the effects of location in the image and no-image condition for each type of instructions. Because there are a relatively small number of subjects in each instruction group, some of the effects described here did not achieve statistical significance, and firm conclusions are therefore inadvisable. Nevertheless, the results are important enough to warrant their presentation.



F(1,24) = 10.30
p = 0.004 **

F(1,24) = 2.20
p = 0.151

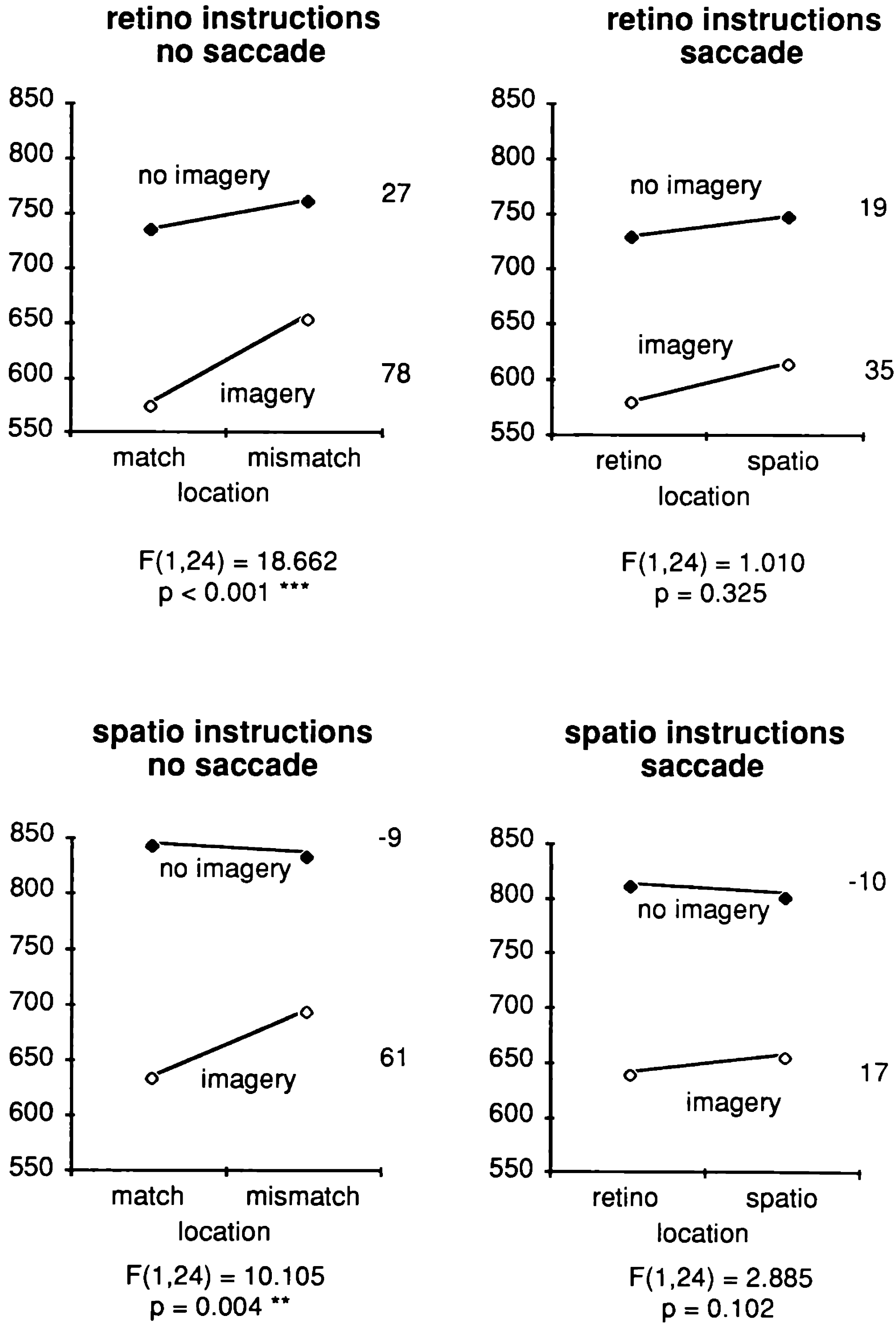


Figure 18: Response times presented separately for the three instruction groups. The numbers to the right of each graph are the

differences between the two location conditions. Below each graph is the result of the statistical test for the interaction of cue type and test stimulus location.

Figure 18 displays means from both no-saccade and saccade trials for the three instruction groups. The values to the right of each graph are the differences between response times for location mismatch and location match, or between spatiotopic and retinotopic location. When there is no saccade, the retinotopic and spatiotopic locations are the same, and thus there should be little difference between the three groups. In fact, the results for no-saccade trials with neutral instructions and retinotopic instructions were almost identical. As discussed earlier, there was in both cases an advantage for the cued location over the uncued location in the no-image condition, which probably stemmed mainly from attentional effects. The larger advantage in the image condition presumably reflects the savings that comes from having the image in the right location. The spatiotopic instructions produced a somewhat different result. In the no-image condition, there was no advantage associated with the cued location, and perhaps there was a slight disadvantage. It almost seems as if subjects were focussing their attention on the retinotopic location that would correspond to the correct spatiotopic location *if* there was an eye movement. Whatever the subjects were doing in this condition, there was still a strong cued-location advantage in the image condition, although it might have been somewhat less than in the other two conditions. In all three groups, the location advantage in imagery is highly significant, as indicated below each graph.

When a saccade occurred, the differences were all diminished somewhat, probably because of the disruption that the saccade introduced. The results in the no-image condition seem to reflect the instructions: responses to the retinotopic location were faster with retinotopic instructions, responses to the spatiotopic location were faster with spatiotopic instructions, and response times were almost equal for the two locations with neutral instructions. This pattern suggests that subjects took note of the instructions and followed them, even though there were always equal numbers of stimuli at each location. In the image condition, the results also varied according to the instructions, but with one important difference: In every case, responses were faster when the stimulus appeared at the retinotopic location. The retinotopic advantage was greater with retinotopic instructions and less with spatiotopic instructions, but it was always in the same direction.

Because of the small number of subjects, this interaction failed to reach significance when the three instruction groups are analyzed individually. This interaction is significant, however, in the overall analysis, as described above. Additionally, in each of the three groups the trend is in the retinotopic direction. Taken together, these results make a strong case for the retinotopic coding of location in the image representations used in mental rotation, regardless of instructions and the allocation of attention.

These results also have implications for the conclusions from Experiment 2. We raised the possibility that the difference between the image and no-image conditions of Experiment 2 might be explained by differences in the allocation of attention between those conditions, and then concluded that such an explanation was not plausible. In the saccade trials of Experiment 3, subjects receiving spatiotopic instructions show a hint of a spatiotopic advantage in the no-image condition and a retinotopic advantage in the image condition. The no-image pattern suggests that subjects are allocating their attention more to the spatiotopic location, in accordance with the instructions. If there is indeed a retinotopic advantage in the imagery condition, then it appears to reflect image location adjustment, and not attention.

General Discussion

From the data in Experiment 3 we conclude that the visual image representations used in mental rotation interact with stimulus representations at a level before a spatiotopic coordinate transform. At this point it is difficult to guess the processing level at which imagery interacts with normal visual perception, but it is probably not not one of the earliest levels. Thus the results from Experiment 3, along with those of Irwin, Brown, & Sun and from the neurophysiology of visual cortex, suggest that the spatiotopic transform does not occur at one of the very early stages of processing, as Feldman suggests. If not, then at what processing stage could we expect the shift to occur?

It might be useful to try to place the coordinate shift in relation to another landmark on the visual processing pathway: The point at which shapes in the visual input are matched against memory representations and categorized. Assuming that there is a single such stage in visual processing, it is the stage at which spatial properties such as location, size, and orientation are factored out and represented separately from shape. In other words, this stage marks the point at which spatially-organized representations are converted to abstract representations. (Note that "spatially-organized" does not mean "spatiotopically-organized." Spatially-organized representations can be coded retinotopically or spatiotopically.) Thus we can ask whether the spatiotopic transform occurs before or after the shift to abstract representations.

As mentioned earlier, the results from Cooper & Shepard's experiment and from numerous other imagery experiments indicate that the representations used in mental rotation are spatially-organized. (Although that claim is fiercely debated. See Pylyshyn, 1973, 1981, & 1984). Likewise, the dot pattern task used by Irwin, Brown, & Sun seems to rely on a spatially-organized representation as well. In this task, subjects must determine the single position in a 3 x 3 grid that is not occupied by a dot in either of two patterns. When the two patterns are superimposed, this task is trivially easy. The task is much more difficult when the two patterns appear at different locations. Presumably in this case subjects rely more on abstract representations of the dot patterns. The form of these abstract representations probably emphasizes general shape properties of the pattern formed by each collection of dots. If so, these shape descriptions cannot easily be combined to determine the one unfilled position.

If the mirror-reversal task and the dots task are both done with retinotopic representations, then are all spatially-organized representations coded retinotopically? The alternative is that a representation that is spatially-organized and spatiotopic exists somewhere in the visual processing stream after the representations used in mental rotation and before the abstract coding. In Feldman's terms, there would be a retinotopic frame and a stable feature frame, but for some reason the stable feature frame would not be the basis for visual imagery (or at least for mental rotation), even though it would be spatially organized. If the spatiotopic transform is postponed until after the level of image representations, then is there much to be gained by doing it before object identification, or might it be postponed until the level of abstract coding?

This question is best considered in relation to Ungerleider & Mishkin's (1982) hypotheses about separate processing streams in the visual system. They present extensive evidence that there is one subsystem in the temporal lobe to identify shapes and a separate subsystem in the posterior parietal lobe to process locations. If a dedicated subsystem is handling location information, then this subsystem probably performs the spatiotopic transform. One advantage would be that the representations that this subsystem employs would be specialized for recording location and would not be complicated by the presence of complex shape information, making the spatiotopic transform that much simpler. Therefore, the representations that contained spatiotopic location coordinates would not include shape information, and the representations in the identity subsystem that included shape information would not be spatiotopically coded. There would be no spatially-organized representation that included shape information and was encoded spatiotopically.

In light of the division of labor between the identity and location subsystems, the findings from Experiments 2 and 3 have important implications for the role of image representations in visual processing. If the identity subsystem specializes in recognizing shapes regardless of location, then it probably utilizes representations that are location-independent. If the representations used in mental rotation are location-specific, as Experiment 2 demonstrated, and if these representations are coded in a retinotopic reference frame, as Experiment 3 demonstrated, then these representations are probably situated at a level of processing before the identity processing stream and the location processing stream diverge.

One way in which visual imagery might be implemented at this processing level is illustrated in a model of high-level visual processing by Kosslyn, Flynn, Amsterdam, & Wang (in press). This model also demonstrates how the spatiotopic shift might be implemented in a system with separate subsystems for identity and location. The first stage of their model uses retinotopically coded representations of the input at a number of different scales. An "attention window" acts to select select a particular area within one of these representations. The selected area is normalized to produce a location-independent and size-independent representation that is then passed on to the identity subsystem. In this process, the retinotopic location of the selected area is passed on to the location subsystem. This subsystem also receives information about head and body position and uses it to transform retinotopic coordinates to spatiotopic coordinates. The abstract representation produced by the identity subsystem is recombined with the spatiotopic location information to make a complete, abstract representation of the visual input. Information can be fed backwards through both the identity and location subsystems to form visual images within the original retinotopic representations.

If there is no spatially-organized representation that is coded spatiotopically, then we must conclude that information from different fixations is not integrated at the level of spatially-organized representations, as Feldman claimed, but instead at the level of abstract representations. This point is also well-illustrated in the model by Kosslyn, Flynn, Amsterdam, & Wang. As the eyes move from position to position, and also as the attention window moves within each fixation, different abstract shape representations produced by the identity subsystem accumulate in an associative memory, each coupled with the appropriate spatiotopic coordinates provided by the location subsystem. Together they form an abstract representation of the environment, coded in spatiotopic coordinates.

In Feldman's view, the lack of a spatially-organized, spatiotopic representation leaves us without a viable substrate for our subjective visual experience. This is a very difficult issue to address. Even though we would describe the visual objects and scenes that we experience as "spatially-organized," we have little basis for concluding that these experiences must be grounded in spatially-organized representations, and not abstract recodings of spatially-organized information. Ultimately it seems more prudent to question the nature of the visual experience than the nature of the mental representation that is suggested by the experimental evidence.

In conclusion, the empirical results presented here provide evidence that subjects engaged in a mental rotation task utilize representations in which location information is coupled with shape information. The represented location can be adjusted, but these adjustments are performed gradually, either smoothly or in small steps. Thus location in these representations appears to be adjusted in a manner similar to that used for size and orientation adjustments. Location adjustments, however can be performed quickly, while orientation adjustments are relatively slow. These representations are coded retinotopically, but it makes little difference in everyday processing, because represented location can be adjusted quickly and easily whenever necessary.

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Appendix 1

Overall analysis from Experiment 1

This appendix contains the results from the analysis of variance including both the shape and no-shape cue trials that was reported in Experiment 1. Included are the means from each main effect and from every interaction that was significant ($p < .05$). Listed below are the factors used in this analysis and the labels associated with them.

cue - type of cue presented before stimulus
- orient - no-shape cue, giving information only about orientation
- both - shape cue, giving information about both shape and orientation

test - character used for test stimulus
- numfour - the digit 4
- letterr - the letter R
- letterj - the letter J

orient - orientation of cue and test stimulus
- (The number in each label gives the orientation in degrees. 0° is the standard orientation, and the value increases as the shape rotates clockwise.)
- ort000
- ort045
- ort090
- ort135
- ort180
- ort225
- ort270
- ort315

hand - handedness of test stimulus
- nor - normal
- mir - mirror reversed

pos - location of test stimulus
- pos1 - upper left
- pos2 - lower left
- pos3 - lower right
- pos4 - upper right

Experiment 1 analysis

SOURCE: cue

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
both					12269	3072	351.4358	193.9189	3.4987
orient					12219	3072	618.4828	424.8714	7.6656

SOURCE: test

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
	numfour				8158	2048	503.4602	339.8925	7.5106
	letterr				8175	2048	457.3911	339.0168	7.4913
	letterj				8155	2048	494.0265	386.1360	8.5325

SOURCE: cue test

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
both	numfour				4087	1024	372.5567	207.5597	6.4862
both	letterr				4093	1024	335.0731	183.4721	5.7335
both	letterj				4089	1024	346.6775	188.1672	5.8802
orient	numfour				4071	1024	634.3638	392.1489	12.2547
orient	letterr				4082	1024	579.7091	407.8755	12.7461
orient	letterj				4066	1024	641.3755	468.4816	14.6401

SOURCE: orient

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
		ort225			3052	768	564.1684	396.4312	14.3050
		ort045			3070	768	393.3102	244.2487	8.8136
		ort135			3061	768	563.7793	387.6347	13.9876
		ort315			3070	768	386.3043	235.6694	8.5040
		ort000			3068	768	353.4801	206.8077	7.4625
		ort270			3062	768	453.7089	289.5550	10.4484
		ort090			3068	768	453.9588	286.5332	10.3394
		ort180			3037	768	710.9643	532.6974	19.2221

SOURCE: cue orient

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
both		ort225			1534	384	392.9351	225.4389	11.5044
both		ort045			1535	384	305.0451	136.1618	6.9485
both		ort135			1534	384	394.9520	214.7562	10.9592
both		ort315			1536	384	310.3822	179.6831	9.1694
both		ort000			1534	384	291.9950	130.8420	6.6770
both		ort270			1535	384	337.4490	152.0890	7.7613
both		ort090			1534	384	340.6059	155.8462	7.9530
both		ort180			1527	384	438.1217	265.2411	13.5355
orient		ort225			1518	384	735.4017	452.8888	23.1114
orient		ort045			1535	384	481.5753	292.0761	14.9049
orient		ort135			1527	384	732.6066	444.5664	22.6867
orient		ort315			1534	384	462.2263	259.5780	13.2465
orient		ort000			1534	384	414.9653	246.8812	12.5986
orient		ort270			1527	384	569.9687	343.0287	17.5051
orient		ort090			1534	384	567.3116	338.1775	17.2575
orient		ort180			1510	384	983.8069	590.4628	30.1319

SOURCE: test orient

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
	numfour	ort225			1015	256	597.4284	394.5001	24.6563
	numfour	ort045			1024	256	419.3828	248.2507	15.5157
	numfour	ort135			1019	256	577.0788	355.0220	22.1889
	numfour	ort315			1023	256	401.1657	240.3170	15.0198
	numfour	ort000			1022	256	381.9505	217.9935	13.6246
	numfour	ort270			1021	256	467.6003	252.0119	15.7507
	numfour	ort090			1023	256	483.5020	304.1871	19.0117
	numfour	ort180			1011	256	699.5736	485.5325	30.3458
	letterr	ort225			1022	256	535.2676	436.8234	27.3015
	letterr	ort045			1022	256	368.6523	225.4313	14.0895
	letterr	ort135			1022	256	511.2682	320.1036	20.0065
	letterr	ort315			1023	256	380.3535	236.2280	14.7643
	letterr	ort000			1023	256	334.8545	189.7840	11.8615
	letterr	ort270			1019	256	429.5251	286.5581	17.9099
	letterr	ort090			1024	256	422.8906	244.4534	15.2783
	letterr	ort180			1020	256	676.3171	506.7424	31.6714
	letterj	ort225			1015	256	559.8092	352.5514	22.0345
	letterj	ort045			1024	256	391.8955	256.3155	16.0197
	letterj	ort135			1020	256	602.9909	467.9361	29.2460
	letterj	ort315			1024	256	377.3936	230.5708	14.4107
	letterj	ort000			1023	256	343.6354	209.3926	13.0870
	letterj	ort270			1022	256	464.0013	325.0709	20.3169
	letterj	ort090			1021	256	455.4837	304.6521	19.0408
	letterj	ort180			1006	256	757.0023	597.9401	37.3713

SOURCE: cue test orient

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
both	numfour	ort225			511	128	427.6608	270.7434	23.9306
both	numfour	ort045			512	128	325.9434	143.1243	12.6505
both	numfour	ort135			510	128	429.8034	249.0500	22.0131
both	numfour	ort315			512	128	325.2461	194.1003	17.1562
both	numfour	ort000			510	128	310.7038	136.6869	12.0815
both	numfour	ort270			511	128	365.6829	144.0103	12.7288
both	numfour	ort090			511	128	352.2930	152.6157	13.4895
both	numfour	ort180			510	128	443.1204	265.8505	23.4981
both	letterr	ort225			512	128	368.6270	206.8205	18.2805
both	letterr	ort045			511	128	288.7721	134.3214	11.8724
both	letterr	ort135			512	128	363.2715	156.9429	13.8719
both	letterr	ort315			512	128	298.9668	144.9429	12.8113
both	letterr	ort000			512	128	277.1270	120.1543	10.6202
both	letterr	ort270			512	128	309.4160	145.6213	12.8712
both	letterr	ort090			512	128	325.5723	146.4534	12.9448
both	letterr	ort180			510	128	448.8320	291.5671	25.7711
both	letterj	ort225			511	128	382.5176	187.8069	16.5999
both	letterj	ort045			512	128	300.4199	129.0608	11.4075
both	letterj	ort135			512	128	391.7813	224.0181	19.8006
both	letterj	ort315			512	128	306.9336	195.7475	17.3018
both	letterj	ort000			512	128	288.1543	133.8568	11.8314
both	letterj	ort270			512	128	337.2480	161.9179	14.3117
both	letterj	ort090			511	128	343.9525	167.7191	14.8244
both	letterj	ort180			507	128	422.4128	236.8312	20.9331
orient	numfour	ort225			504	128	767.1960	425.5445	37.6132
orient	numfour	ort045			512	128	512.8223	292.6741	25.8690
orient	numfour	ort135			509	128	724.3542	383.8308	33.9262
orient	numfour	ort315			511	128	477.0853	258.1976	22.8217
orient	numfour	ort000			512	128	453.1973	257.8780	22.7934
orient	numfour	ort270			510	128	569.5176	292.9901	25.8969
orient	numfour	ort090			512	128	614.7109	357.4827	31.5973
orient	numfour	ort180			501	128	956.0267	519.7031	45.9357
orient	letterr	ort225			510	128	701.9082	533.2744	47.1352
orient	letterr	ort045			511	128	448.5326	266.7101	23.5741
orient	letterr	ort135			510	128	659.2650	370.0776	32.7105
orient	letterr	ort315			511	128	461.7402	278.7228	24.6359
orient	letterr	ort000			511	128	392.5820	226.1969	19.9932
orient	letterr	ort270			507	128	549.6341	338.5152	29.9208
orient	letterr	ort090			512	128	520.2090	281.8616	24.9133
orient	letterr	ort180			510	128	903.8021	571.2026	50.4877
orient	letterj	ort225			504	128	737.1009	388.5005	34.3389
orient	letterj	ort045			512	128	483.3711	313.6694	27.7247
orient	letterj	ort135			508	128	814.2005	547.3087	48.3757
orient	letterj	ort315			512	128	447.8535	241.7022	21.3637
orient	letterj	ort000			511	128	399.1165	252.8108	22.3455
orient	letterj	ort270			510	128	590.7546	391.8814	34.6377
orient	letterj	ort090			510	128	567.0150	364.9007	32.2530
orient	letterj	ort180			499	128	1091.5918	660.3997	58.3716

SOURCE: hand

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
			mir		12238	3072	552.6282	391.2345	7.0587
			nor		12250	3072	417.2904	302.5944	5.4595

SOURCE: orient hand

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
		ort225	mir		1523	384	650.8127	453.4194	23.1385

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
		ort225	nor		1529	384	477.5241	306.7293	15.6527
		ort045	mir		1535	384	452.1174	274.2572	13.9956
		ort045	nor		1535	384	334.5030	193.1812	9.8582
		ort135	mir		1530	384	623.8385	436.6278	22.2816
		ort135	nor		1531	384	503.7201	320.9934	16.3806
		ort315	mir		1535	384	445.8223	253.7222	12.9477
		ort315	nor		1535	384	326.7862	199.3663	10.1739
		ort000	mir		1533	384	409.1417	233.9529	11.9389
		ort000	nor		1535	384	297.8186	157.1749	8.0208
		ort270	mir		1527	384	516.6107	320.0201	16.3310
		ort270	nor		1535	384	390.8071	239.9089	12.2428
		ort090	mir		1535	384	518.3533	317.5311	16.2039
		ort090	nor		1533	384	389.5642	235.1083	11.9978
		ort180	mir		1520	384	804.3288	557.2793	28.4385
		ort180	nor		1517	384	617.5998	490.1372	25.0122

SOURCE: pos

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
				pos4	6121	1536	480.9393	365.0799	9.3152
				pos1	6115	1536	486.4123	367.4032	9.3745
				pos2	6125	1536	487.7350	342.8431	8.7478
				pos3	6127	1536	484.7505	349.1523	8.9088

SOURCE: orient pos

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
		ort225		pos4	761	192	581.4032	439.4572	31.7151
		ort225		pos1	763	192	567.2743	440.7483	31.8083
		ort225		pos2	763	192	547.6723	346.7827	25.0269
		ort225		pos3	765	192	560.3238	350.5175	25.2964
		ort045		pos4	767	192	378.6645	234.4563	16.9204
		ort045		pos1	768	192	391.8893	225.3114	16.2604
		ort045		pos2	767	192	412.5477	270.9033	19.5508
		ort045		pos3	768	192	390.1393	244.6290	17.6546
		ort135		pos4	766	192	543.2470	356.3369	25.7164
		ort135		pos1	764	192	607.4319	483.6048	34.9012
		ort135		pos2	765	192	575.3351	368.6537	26.6053
		ort135		pos3	766	192	529.1033	320.8821	23.1577
		ort315		pos4	768	192	384.6693	219.2419	15.8224
		ort315		pos1	768	192	371.8620	227.3097	16.4047
		ort315		pos2	767	192	387.0074	237.2336	17.1209
		ort315		pos3	767	192	401.6784	258.0033	18.6198
		ort000		pos4	768	192	338.7461	212.4274	15.3306
		ort000		pos1	766	192	347.8576	182.5382	13.1736
		ort000		pos2	768	192	360.0313	221.1589	15.9608
		ort000		pos3	766	192	367.2856	209.5420	15.1224
		ort270		pos4	765	192	452.0538	310.1109	22.3803
		ort270		pos1	765	192	446.1727	278.8208	20.1222
		ort270		pos2	767	192	444.4253	264.5054	19.0890
		ort270		pos3	765	192	472.1836	303.8465	21.9282
		ort090		pos4	767	192	452.1688	308.8429	22.2888
		ort090		pos1	765	192	448.8420	287.7015	20.7631
		ort090		pos2	768	192	472.9336	286.1651	20.6522
		ort090		pos3	768	192	441.8906	262.8880	18.9723
		ort180		pos4	759	192	716.5616	547.4066	39.5057
		ort180		pos1	756	192	709.9688	494.3442	35.6762
		ort180		pos2	760	192	701.9275	515.9620	37.2364
		ort180		pos3	762	192	715.3993	573.7089	41.4039

SOURCE: cue orient pos

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
both		ort225		pos4	383	96	391.1597	265.2743	27.0744
both		ort225		pos1	384	96	392.6693	234.5571	23.9394
both		ort225		pos2	383	96	401.5182	219.2980	22.3820
both		ort225		pos3	384	96	386.3932	176.9056	18.0554
both		ort045		pos4	383	96	301.0061	140.7018	14.3603
both		ort045		pos1	384	96	300.3464	130.7799	13.3477
both		ort045		pos2	384	96	316.8958	145.8156	14.8822
both		ort045		pos3	384	96	301.9323	128.0336	13.0674
both		ort135		pos4	384	96	391.0573	235.3261	24.0179
both		ort135		pos1	383	96	412.4531	225.4049	23.0053
both		ort135		pos2	384	96	390.4557	216.6984	22.1167
both		ort135		pos3	383	96	385.8420	179.9008	18.3610
both		ort315		pos4	384	96	289.7708	134.6675	13.7444
both		ort315		pos1	384	96	305.4583	151.2058	15.4324
both		ort315		pos2	384	96	324.1667	217.9289	22.2423
both		ort315		pos3	384	96	322.1328	202.2046	20.6374
both		ort000		pos4	384	96	284.7734	132.2910	13.5019
both		ort000		pos1	383	96	293.1120	133.6854	13.6442
both		ort000		pos2	384	96	296.1797	136.6767	13.9495
both		ort000		pos3	383	96	293.9149	122.0268	12.4543
both		ort270		pos4	383	96	328.6319	149.4505	15.2532
both		ort270		pos1	384	96	330.7240	150.0706	15.3165
both		ort270		pos2	384	96	349.4688	164.9808	16.8383
both		ort270		pos3	384	96	340.9714	144.5565	14.7537
both		ort090		pos4	383	96	334.4757	129.5737	13.2246
both		ort090		pos1	383	96	337.5469	168.7661	17.2246
both		ort090		pos2	384	96	347.0104	160.7922	16.4108
both		ort090		pos3	384	96	343.3906	163.3919	16.6761
both		ort180		pos4	382	96	436.0521	255.1805	26.0442
both		ort180		pos1	380	96	446.6102	281.9047	28.7718
both		ort180		pos2	383	96	448.5408	288.3874	29.4334
both		ort180		pos3	382	96	421.2839	235.3827	24.0236
orient		ort225		pos4	378	96	771.6467	494.7329	50.4935
orient		ort225		pos1	379	96	741.8793	523.3835	53.4176
orient		ort225		pos2	380	96	693.8264	387.9678	39.5968
orient		ort225		pos3	381	96	734.2543	393.1693	40.1277
orient		ort045		pos4	384	96	456.3229	280.2366	28.6015
orient		ort045		pos1	384	96	483.4323	260.8156	26.6194
orient		ort045		pos2	383	96	508.1997	328.3235	33.5094
orient		ort045		pos3	384	96	478.3464	296.9836	30.3108
orient		ort135		pos4	382	96	695.4366	391.2789	39.9347
orient		ort135		pos1	381	96	802.4106	585.2931	59.7362
orient		ort135		pos2	381	96	760.2144	396.4886	40.4664
orient		ort135		pos3	383	96	672.3646	364.9254	37.2450
orient		ort315		pos4	384	96	479.5677	245.5680	25.0632
orient		ort315		pos1	384	96	438.2656	268.5301	27.4067
orient		ort315		pos2	383	96	449.8481	240.1623	24.5115
orient		ort315		pos3	383	96	481.2240	283.1205	28.8959
orient		ort000		pos4	384	96	392.7188	259.4947	26.4846
orient		ort000		pos1	383	96	402.6033	207.5141	21.1793
orient		ort000		pos2	384	96	423.8828	267.2395	27.2750
orient		ort000		pos3	383	96	440.6563	250.0151	25.5171
orient		ort270		pos4	382	96	575.4757	374.4699	38.2192
orient		ort270		pos1	381	96	561.6215	326.8666	33.3607
orient		ort270		pos2	383	96	539.3819	308.5784	31.4942
orient		ort270		pos3	381	96	603.3958	360.4510	36.7884
orient		ort090		pos4	384	96	569.8620	383.3897	39.1295
orient		ort090		pos1	382	96	560.1372	336.0053	34.2934
orient		ort090		pos2	384	96	598.8568	326.7135	33.3451
orient		ort090		pos3	384	96	540.3906	304.3715	31.0648
orient		ort180		pos4	377	96	997.0712	615.0751	62.7758
orient		ort180		pos1	376	96	973.3273	521.2283	53.1976
orient		ort180		pos2	377	96	955.3142	567.7211	57.9428
orient		ort180		pos3	380	96	1009.5148	656.8977	67.0443

SOURCE: orient hand pos

cue	test	orient	hand	pos	n	N	MEAN	SD	SE
		ort225	mir	pos4	380	96	688.0816	495.7764	50.6000
		ort225	mir	pos1	382	96	638.2231	533.4195	54.4419
		ort225	mir	pos2	379	96	650.7925	384.1815	39.2104
		ort225	mir	pos3	382	96	626.1536	385.6744	39.3627
		ort225	nor	pos4	381	96	474.7248	345.6643	35.2792
		ort225	nor	pos1	381	96	496.3255	309.6017	31.5986
		ort225	nor	pos2	384	96	444.5521	269.6211	27.5181
		ort225	nor	pos3	383	96	494.4939	299.1909	30.5360
		ort045	mir	pos4	383	96	453.2795	273.3946	27.9032

ort045	mir	pos1	384	96	437.7422	234.9399	23.9785
ort045	mir	pos2	384	96	473.2292	312.3501	31.8791
ort045	mir	pos3	384	96	444.2188	273.8900	27.9538
ort045	nor	pos4	384	96	304.0495	156.5937	15.9823
ort045	nor	pos1	384	96	346.0365	206.4432	21.0700
ort045	nor	pos2	383	96	351.8663	206.2647	21.0518
ort045	nor	pos3	384	96	336.0599	198.4695	20.2562
ort135	mir	pos4	384	96	558.4948	344.1803	35.1278
ort135	mir	pos1	381	96	714.8533	594.3194	60.6575
ort135	mir	pos2	383	96	633.0625	395.2084	40.3358
ort135	mir	pos3	382	96	588.9436	355.9892	36.3330
ort135	nor	pos4	382	96	527.9991	369.2676	37.6882
ort135	nor	pos1	383	96	500.0104	306.0587	31.2370
ort135	nor	pos2	382	96	517.6076	332.1400	33.8989
ort135	nor	pos3	384	96	469.2630	270.2760	27.5849
ort315	mir	pos4	384	96	446.4323	233.1678	23.7976
ort315	mir	pos1	384	96	447.5677	267.4279	27.2942
ort315	mir	pos2	384	96	424.3281	234.2711	23.9102
ort315	mir	pos3	383	96	464.9609	279.1495	28.4906
ort315	nor	pos4	384	96	322.9063	185.9116	18.9745
ort315	nor	pos1	384	96	296.1563	144.1606	14.7133
ort315	nor	pos2	383	96	349.6866	235.4868	24.0343
ort315	nor	pos3	384	96	338.3958	218.6641	22.3173
ort000	mir	pos4	384	96	394.3385	238.6751	24.3597
ort000	mir	pos1	382	96	390.1450	179.5068	18.3208
ort000	mir	pos2	384	96	423.9479	266.8586	27.2361
ort000	mir	pos3	383	96	428.1354	243.0844	24.8097
ort000	nor	pos4	384	96	283.1536	165.8731	16.9294
ort000	nor	pos1	384	96	305.5703	176.5060	18.0146
ort000	nor	pos2	384	96	296.1146	137.3578	14.0190
ort000	nor	pos3	383	96	306.4358	147.3246	15.0363
ort270	mir	pos4	382	96	514.7622	364.8148	37.2338
ort270	mir	pos1	381	96	517.9835	305.4608	31.1760
ort270	mir	pos2	383	96	513.0252	297.1795	30.3308
ort270	mir	pos3	381	96	520.6719	313.2710	31.9731
ort270	nor	pos4	383	96	309.3455	228.7193	23.3436
ort270	nor	pos1	384	96	374.3620	229.2857	23.4014
ort270	nor	pos2	384	96	375.8255	206.9688	21.1237
ort270	nor	pos3	384	96	423.6953	287.6227	29.3554
ort090	mir	pos4	384	96	527.5026	372.3664	38.0045
ort090	mir	pos1	383	96	513.5851	309.2481	31.5625
ort090	mir	pos2	384	96	536.8177	301.6446	30.7865
ort090	mir	pos3	384	96	495.5078	283.2451	28.9086
ort090	nor	pos4	383	96	376.8351	204.0721	20.8280
ort090	nor	pos1	382	96	384.0990	249.6189	25.4766
ort090	nor	pos2	384	96	409.0495	255.7444	26.1018
ort090	nor	pos3	384	96	388.2734	230.0213	23.4765
ort180	mir	pos4	380	96	783.0148	561.9084	57.3495
ort180	mir	pos1	377	96	833.4878	534.4640	54.5485
ort180	mir	pos2	381	96	791.6415	531.0848	54.2036
ort180	mir	pos3	382	96	809.1710	605.8872	61.8381
ort180	nor	pos4	379	96	650.1085	527.0637	53.7932
ort180	nor	pos1	379	96	586.4497	418.1361	42.6758
ort180	nor	pos2	379	96	612.2135	486.7424	49.6779
ort180	nor	pos3	380	96	621.6276	526.1918	53.7042

FACTOR:	subj	cue	test	orient	hand	pos	time
LEVELS:	16	2	3	8	2	4	6144
TYPE :	RANDOM	WITHIN	WITHIN	WITHIN	WITHIN	WITHIN	DATA

SOURCE	SS	df	MS	F	p	
cue	109538488.8353	1	109538488.8353	31.768	0.000	***
cs/	51720877.4706	15	3448058.4980			
test	2425863.8512	2	1212931.9256	8.570	0.001	**
ts/	4245932.4476	30	141531.0816			
ct	662673.7599	2	331336.8799	3.774	0.035	*
cts/	2633741.0218	30	87791.3674			
orient	77507863.2860	7	11072551.8980	55.059	0.000	***
os/	21116045.7364	105	201105.1975			
co	25604231.3936	7	3657747.3419	21.675	0.000	***
cos/	17719518.3572	105	168757.3177			
to	1538546.4108	14	109896.1722	2.474	0.003	**
tos/	9328367.5191	210	44420.7977			
cto	1926933.2615	14	137638.0901	2.916	0.000	***
ctos/	9912325.9917	210	47201.5523			
hand	28133860.2234	1	28133860.2234	41.359	0.000	***
hs/	10203549.8711	15	680236.6581			
ch	1791643.3278	1	1791643.3278	4.038	0.063	
chs/	6655544.8015	15	443702.9868			
th	31583.1058	2	15791.5529	0.127	0.881	
ths/	3736793.1325	30	124559.7711			
cth	492989.4200	2	246494.7100	2.986	0.066	
cths/	2476354.2097	30	82545.1403			
oh	1075834.0127	7	153690.5732	2.180	0.042	*
ohs/	7402937.3533	105	70504.1653			
coh	56944.5371	7	8134.9339	0.127	0.996	
cohs/	6705370.5682	105	63860.6721			
toh	533609.7628	14	38114.9831	0.637	0.833	
tohs/	12571181.4950	210	59862.7690			
ctoh	612354.4205	14	43739.6015	0.910	0.549	
ctohs/	10095340.7506	210	48073.0512			
pos	39966.7513	3	13322.2504	0.689	0.563	
ps/	869667.5655	45	19325.9459			
cp	56587.9269	3	18862.6423	0.966	0.417	
cps/	878455.3371	45	19521.2297			
tp	129274.4025	6	21545.7337	0.679	0.667	
tps/	2857546.6589	90	31750.5184			
ctp	47931.0402	6	7988.5067	0.320	0.925	
ctps/	2248938.5553	90	24988.2062			
op	1292398.3601	21	61542.7791	2.059	0.005	**
ops/	9415125.9004	315	29889.2886			
cop	1105651.6966	21	52650.0808	1.935	0.009	**
cops/	8572043.6946	315	27212.8371			
top	1088590.9080	42	25918.8311	0.831	0.769	
tops/	19660315.9365	630	31206.8507			
ctop	883931.1264	42	21045.9792	0.754	0.872	
ctops/	17596043.1143	630	27930.2272			
hp	143604.1935	3	47868.0645	1.350	0.270	
hps/	1595721.5434	45	35460.4787			
chp	53624.9575	3	17874.9858	0.522	0.669	
chps/	1540068.3743	45	34223.7417			

thp	154296.0732	6	25716.0122	0.960	0.457	
thps/	2410952.0117	90	26788.3557			
cthp	170193.9078	6	28365.6513	1.446	0.206	
cthps/	1765431.8219	90	19615.9091			
ohp	1642658.8723	21	78221.8511	2.520	0.000	***
ohps/	9779467.2551	315	31045.9278			
cohp	409320.4854	21	19491.4517	0.583	0.929	
cohps/	10534763.0998	315	33443.6924			
tohp	1206519.8106	42	28726.6622	1.051	0.386	
tohps/	17215313.4494	630	27325.8944			
ctohp	1452673.3562	42	34587.4609	1.283	0.113	
ctohps/	16985383.7088	630	26960.9265			

Appendix 2

Overall analysis from Experiment 2

This appendix contains the results from the analysis of variance reported in Experiment 2. Included are the means from each main effect and from every interaction that was significant ($p < .05$). Listed below are the factors used in this analysis and the labels associated with them.

cue - type of cue presented before stimulus
- orient - no-image (no-shape) cue
- both - image (shape) cue

shape - character used for test stimulus
- numfour - the digit 4
- letterr - the letter R
- letterj - the letter J

horz - location of cue
- 0 - on left
- 1 - on right

orient - orientation of cue and test stimulus in degrees
- 45
- 135
- 225
- 315

mirr - handedness of test stimulus
- 0 - normal
- 1 - mirror reversed

dis - distance between cue and stimulus
- 0 - same location as cue
- 1 - 1.9 cm from cue
- 2 - 8.3 cm from cue
- 3 - 11.0 cm from cue

vert - placement of stimulus in relation to cue
- hi - in the direction towards the top of the imaginary circle
- lo - in the direction towards the bottom

Experiment 2 analysis   Thu May 11 15:19:40 1989   1

SOURCE: cue

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient							8640	5760	643.7359	313.7203	4.1336
both							8640	5760	491.0638	226.0070	2.9779

SOURCE: shape

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
	numfour						5760	3840	604.9878	319.1001	5.1495
	letterj						5760	3840	570.9118	293.4553	4.7356
	letterr						5760	3840	526.3000	225.1641	3.6336

SOURCE: cue shape

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient	numfour						2880	1920	684.0536	361.1589	8.2423
orient	letterj						2880	1920	658.0042	330.1463	7.5345
orient	letterr						2880	1920	589.1500	226.0979	5.1600
both	numfour						2880	1920	525.9220	246.4909	5.6254
both	letterj						2880	1920	483.8194	219.3223	5.0053
both	letterr						2880	1920	463.4500	205.9115	4.6993

SOURCE: horz

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
		1					8640	5760	565.6429	265.5198	3.4985
		0					8640	5760	569.1568	301.0798	3.9671

SOURCE: orient

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
			315				4320	2880	491.7527	213.1122	3.9711
			225				4320	2880	638.6550	304.2446	5.6693
			45				4320	2880	491.4315	246.6177	4.5954
			135				4320	2880	647.7604	317.0636	5.9081

SOURCE: cue orient

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient			315				2160	1440	541.0199	213.8569	5.6356
orient			225				2160	1440	732.4169	320.3448	8.4418
orient			45				2160	1440	548.8653	308.6374	8.1333
orient			135				2160	1440	752.6417	333.1233	8.7786
both			315				2160	1440	442.4854	200.6801	5.2884
both			225				2160	1440	544.8931	254.9083	6.7174
both			45				2160	1440	433.9977	140.7974	3.7103
both			135				2160	1440	542.8792	261.0400	6.8790

SOURCE: cue shape orient

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient	numfour		315				720	480	582.4035	259.1384	11.8280
orient	numfour		225				720	480	770.9604	311.0401	14.1970
orient	numfour		45				720	480	608.6618	452.1920	20.6396
orient	numfour		135				720	480	774.1889	349.8910	15.9703
orient	letterj		315				720	480	538.3215	176.3358	8.0486
orient	letterj		225				720	480	755.3451	394.0502	17.9858
orient	letterj		45				720	480	546.5569	227.2506	10.3725
orient	letterj		135				720	480	791.7931	380.0317	17.3460
orient	letterr		315				720	480	502.3347	189.5393	8.6512
orient	letterr		225				720	480	670.9451	224.6490	10.2538
orient	letterr		45				720	480	491.3771	152.1452	6.9444
orient	letterr		135				720	480	691.9431	246.6488	11.2579
both	numfour		315				720	480	474.4694	221.8265	10.1249
both	numfour		225				720	480	578.0410	279.5380	12.7591
both	numfour		45				720	480	466.8521	144.6678	6.6032
both	numfour		135				720	480	584.3257	287.8275	13.1375
both	letterj		315				720	480	438.5417	214.7684	9.8028
both	letterj		225				720	480	553.1097	253.4829	11.5699
both	letterj		45				720	480	427.9729	145.8703	6.6580
both	letterj		135				720	480	515.6535	223.7115	10.2110
both	letterr		315				720	480	414.4451	154.3523	7.0452
both	letterr		225				720	480	503.5285	223.4450	10.1988
both	letterr		45				720	480	407.1681	124.5318	5.6841
both	letterr		135				720	480	528.6583	262.9675	12.0028

SOURCE: mirr

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
				0			8640	5760	521.2796	254.2957	3.3506
				1			8640	5760	613.5202	303.7018	4.0016

SOURCE: orient mirr

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
			315	0			2160	1440	452.9683	193.8153	5.1075
			315	1			2160	1440	530.5370	224.2550	5.9096
			225	0			2160	1440	579.2426	262.2817	6.9117
			225	1			2160	1440	698.0674	330.6624	8.7137
			45	0			2160	1440	453.6361	216.0482	5.6934
			45	1			2160	1440	529.2269	268.6019	7.0783
			135	0			2160	1440	599.2713	295.0757	7.7759
			135	1			2160	1440	696.2495	330.6859	8.7143

SOURCE: cue orient mirr

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient			315	0			1080	720	497.4653	182.8501	6.8144
orient			315	1			1080	720	584.5745	233.0230	8.6843
orient			225	0			1080	720	683.9069	277.0129	10.3237
orient			225	1			1080	720	780.9269	352.0443	13.1199
orient			45	0			1080	720	510.3491	269.6267	10.0484
orient			45	1			1080	720	587.3815	339.0824	12.6369
orient			135	0			1080	720	720.4986	312.7065	11.6539
orient			135	1			1080	720	784.7847	349.6312	13.0300
both			315	0			1080	720	408.4713	194.3742	7.2439
both			315	1			1080	720	476.4995	201.2525	7.5002
both			225	0			1080	720	474.5782	197.4922	7.3601
both			225	1			1080	720	615.2079	284.8537	10.6159
both			45	0			1080	720	396.9231	119.4922	4.4532
both			45	1			1080	720	471.0722	150.4796	5.6080
both			135	0			1080	720	478.0440	216.8918	8.0831
both			135	1			1080	720	607.7144	284.4602	10.6012

SOURCE: dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
					0		8640	2880	535.9718	215.7622	4.0205
					2		2880	2880	588.7628	305.5361	5.6933
					1		2880	2880	548.7628	272.3864	5.0756
					3		2880	2880	596.1021	325.0413	6.0568

SOURCE: cue dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient					0		4320	1440	625.7667	232.7377	6.1332
orient					2		1440	1440	656.7500	343.8927	9.0624
orient					1		1440	1440	625.5493	276.1046	7.2760
orient					3		1440	1440	666.8778	379.2948	9.9953
both					0		4320	1440	446.1769	151.1115	3.9821
both					2		1440	1440	520.7757	243.4263	6.4148
both					1		1440	1440	471.9764	245.7763	6.4768
both					3		1440	1440	525.3264	239.7649	6.3184

SOURCE: horz dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
		1			0		4320	1440	541.9468	219.0625	5.7728
		1			2		1440	1440	580.9861	253.1878	6.6721
		1			1		1440	1440	555.5417	280.4158	7.3896
		1			3		1440	1440	584.0972	300.3069	7.9138
		0			0		4320	1440	529.9968	212.3186	5.5951
		0			2		1440	1440	596.5396	350.0634	9.2250
		0			1		1440	1440	541.9840	264.0364	6.9580
		0			3		1440	1440	608.1069	347.7132	9.1630

SOURCE: cue shape horz dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient	numfour	1			0		720	240	656.6375	247.9913	16.0078

orient	numfour	1	2	240	240	685.4250	287.1019	18.5323
orient	numfour	1	1	240	240	668.7083	273.8611	17.6777
orient	numfour	1	3	240	240	726.5292	477.4148	30.8170
orient	numfour	0	0	720	240	647.9375	246.3484	15.9017
orient	numfour	0	2	240	240	733.0125	579.6034	37.4132
orient	numfour	0	1	240	240	643.2875	264.0754	17.0460
orient	numfour	0	3	240	240	710.8917	353.8038	22.8379
orient	letterj	1	0	720	240	651.6694	249.9628	16.1350
orient	letterj	1	2	240	240	657.0458	277.0459	17.8832
orient	letterj	1	1	240	240	651.0167	351.9216	22.7164
orient	letterj	1	3	240	240	645.6792	297.6276	19.2118
orient	letterj	0	0	720	240	639.1222	239.0311	15.4294
orient	letterj	0	2	240	240	687.2500	309.2100	19.9594
orient	letterj	0	1	240	240	634.8042	276.5755	17.8529
orient	letterj	0	3	240	240	697.4458	539.1615	34.8027
orient	letterr	1	0	720	240	590.5194	196.9367	12.7122
orient	letterr	1	2	240	240	589.3792	222.9170	14.3892
orient	letterr	1	1	240	240	570.7125	223.4511	14.4237
orient	letterr	1	3	240	240	594.8875	225.1645	14.5343
orient	letterr	0	0	720	240	568.7139	196.7893	12.7027
orient	letterr	0	2	240	240	588.3875	234.0328	15.1068
orient	letterr	0	1	240	240	584.7667	237.4337	15.3263
orient	letterr	0	3	240	240	625.8333	263.2767	16.9944
both	numfour	1	0	720	240	485.1111	171.6900	11.0825
both	numfour	1	2	240	240	576.6125	274.6686	17.7298
both	numfour	1	1	240	240	505.8292	248.7561	16.0571
both	numfour	1	3	240	240	534.7042	189.6490	12.2418
both	numfour	0	0	720	240	457.4569	134.9604	8.7117
both	numfour	0	2	240	240	560.9583	314.0354	20.2709
both	numfour	0	1	240	240	496.3458	246.0316	15.8813
both	numfour	0	3	240	240	590.3583	303.2944	19.5776
both	letterj	1	0	720	240	440.1833	148.0709	9.5579
both	letterj	1	2	240	240	493.5875	163.2233	10.5360
both	letterj	1	1	240	240	462.6750	200.6289	12.9505
both	letterj	1	3	240	240	521.4042	228.8720	14.7736
both	letterj	0	0	720	240	441.0306	158.0006	10.1989
both	letterj	0	2	240	240	513.3958	235.5712	15.2061
both	letterj	0	1	240	240	466.3167	298.3029	19.2554
both	letterj	0	3	240	240	531.9625	257.5964	16.6278
both	letterr	1	0	720	240	427.5597	142.5371	9.2007
both	letterr	1	2	240	240	483.8667	202.5148	13.0723
both	letterr	1	1	240	240	474.3083	287.2615	18.5426
both	letterr	1	3	240	240	481.3792	214.8212	13.8666
both	letterr	0	0	720	240	425.7194	141.7994	9.1531
both	letterr	0	2	240	240	496.2333	228.1376	14.7262
both	letterr	0	1	240	240	426.3833	159.9174	10.3226
both	letterr	0	3	240	240	492.1500	214.1160	13.8211

SOURCE: horz orient dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
		1	315		0		1080	360	461.7991	137.2483	7.2336
		1	315		2		360	360	507.5917	167.4359	8.8246
		1	315		1		360	360	475.4194	182.4801	9.6175
		1	315		3		360	360	490.5083	200.4293	10.5636
		1	225		0		1080	360	615.6407	245.6618	12.9475
		1	225		2		360	360	655.7500	289.6345	15.2651
		1	225		1		360	360	621.5556	318.3388	16.7779
		1	225		3		360	360	661.0111	315.5690	16.6319
		1	45		0		1080	360	469.8750	147.0011	7.7476
		1	45		2		360	360	501.5194	168.8225	8.8977
		1	45		1		360	360	477.1250	171.1322	9.0195
		1	45		3		360	360	524.0528	340.3485	17.9379
		1	135		0		1080	360	620.4722	261.3018	13.7718
		1	135		2		360	360	659.0833	305.0774	16.0790
		1	135		1		360	360	648.0667	354.5504	18.6864
		1	135		3		360	360	660.8167	285.7703	15.0614
		0	315		0		1080	360	463.5028	153.5139	8.0909
		0	315		2		360	360	523.2417	294.1386	15.5025
		0	315		1		360	360	487.7278	282.0818	14.8670
		0	315		3		360	360	524.2306	223.4596	11.7774
		0	225		0		1080	360	579.9157	235.5525	12.4147
		0	225		2		360	360	659.7722	286.3929	15.0942
		0	225		1		360	360	612.3806	274.3816	14.4612
		0	225		3		360	360	703.2139	417.1010	21.9832
		0	45		0		1080	360	463.0157	137.7097	7.2579
		0	45		2		360	360	514.8056	372.8223	19.6495
		0	45		1		360	360	468.4583	185.6949	9.7870
		0	45		3		360	360	512.6000	309.6688	16.3210
		0	135		0		1080	360	613.5528	253.4665	13.3589
		0	135		2		360	360	688.3389	398.8985	21.0238
		0	135		1		360	360	599.3694	271.0363	14.2849
		0	135		3		360	360	692.3833	363.9111	19.1798

SOURCE: mirr dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
				0	0		4320	1440	497.7155	204.9673	5.4014
				0	2		1440	1440	535.1340	241.6186	6.3672
				0	1		1440	1440	507.1389	267.8926	7.0596
				0	3		1440	1440	545.1299	291.7625	7.6886
				1	0		4320	1440	574.2280	219.5410	5.7854
				1	2		1440	1440	642.3917	350.1912	9.2283
				1	1		1440	1440	590.3868	270.5665	7.1301
				1	3		1440	1440	647.0743	347.9250	9.1686

SOURCE: shape mirr dis

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
	numfour			0	0		1440	480	522.8458	221.2766	10.0998
	numfour			0	2		480	480	567.9479	257.8058	11.7672
	numfour			0	1		480	480	522.2313	235.7850	10.7621
	numfour			0	3		480	480	598.2562	381.9050	17.4315
	numfour			1	0		1440	480	600.7257	222.2290	10.1433
	numfour			1	2		480	480	710.0563	479.0864	21.8672
	numfour			1	1		480	480	634.8542	289.0552	13.1935
	numfour			1	3		480	480	682.9854	321.9257	14.6938
	letterj			0	0		1440	480	508.2458	212.6467	9.7060
	letterj			0	2		480	480	541.4896	244.6534	11.1668
	letterj			0	1		480	480	523.2896	333.0330	15.2008
	letterj			0	3		480	480	533.0208	234.8424	10.7190
	letterj			1	0		1440	480	577.7569	237.6815	10.8486
	letterj			1	2		480	480	634.1500	278.2204	12.6990
	letterj			1	1		480	480	584.1167	260.1906	11.8760
	letterj			1	3		480	480	665.2250	442.4883	20.1967
	letterr			0	0		1440	480	462.0549	173.2338	7.9070
	letterr			0	2		480	480	495.9646	215.4213	9.8326
	letterr			0	1		480	480	475.8958	218.2331	9.9609
	letterr			0	3		480	480	504.1125	223.7586	10.2131
	letterr			1	0		1440	480	544.2014	193.1276	8.8150
	letterr			1	2		480	480	582.9688	230.8434	10.5365
	letterr			1	1		480	480	552.1896	255.3222	11.6538
	letterr			1	3		480	480	593.0125	244.2899	11.1503

SOURCE: vert

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
						hi	8640	5760	567.4152	292.5531	3.8547
						lo	8640	5760	567.3846	274.8976	3.6221

SOURCE: cue mirr vert

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient				0		hi	2160	1440	602.5336	270.1853	7.1200
orient				0		lo	2160	1440	603.5764	295.4313	7.7853
orient				1		hi	2160	1440	688.1998	375.8906	9.9056
orient				1		lo	2160	1440	680.6340	292.6769	7.7127
both				0		hi	2160	1440	444.4542	205.3243	5.4108
both				0		lo	2160	1440	434.5542	171.8870	4.5296
both				1		hi	2160	1440	534.4731	232.4363	6.1252
both				1		lo	2160	1440	550.7738	260.5194	6.8653

Experiment 2 analysis

Thu May 11 15:19:40 1989

SOURCE: orient mirr vert

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
			315	0		hi	1080	720	463.9556	218.2101	8.1322
			315	0		lo	1080	720	441.9810	165.2983	6.1603
			315	1		hi	1080	720	524.6551	212.4339	7.9169
			315	1		lo	1080	720	536.4190	235.4848	8.7760
			225	0		hi	1080	720	575.2704	251.6528	9.3785
			225	0		lo	1080	720	583.2148	272.6137	10.1597
			225	1		hi	1080	720	696.5639	355.5086	13.2490
			225	1		lo	1080	720	699.5708	304.0337	11.3307
			45	0		hi	1080	720	451.2282	170.7469	6.3634
			45	0		lo	1080	720	456.0440	253.4807	9.4467
			45	1		hi	1080	720	532.5407	290.0466	10.8094
			45	1		lo	1080	720	525.9130	245.4492	9.1474
			135	0		hi	1080	720	603.5213	312.2881	11.6383
			135	0		lo	1080	720	595.0213	276.9484	10.3213
			135	1		hi	1080	720	691.5861	362.5898	13.5129
			135	1		lo	1080	720	700.9130	295.5393	11.0141

SOURCE: cue orient mirr vert

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient			315	0		hi	540	360	504.6833	175.9695	9.2744
orient			315	0		lo	540	360	490.2472	189.4510	9.9849
orient			315	1		hi	540	360	574.6435	222.1895	11.7104
orient			315	1		lo	540	360	594.5056	243.2792	12.8219
orient			225	0		hi	540	360	672.0333	260.3889	13.7237
orient			225	0		lo	540	360	695.7806	292.5763	15.4201
orient			225	1		hi	540	360	800.4343	415.6922	21.9089
orient			225	1		lo	540	360	761.4194	273.2260	14.4003
orient			45	0		hi	540	360	504.1713	197.2656	10.3968
orient			45	0		lo	540	360	516.5269	326.5109	17.2086
orient			45	1		hi	540	360	590.9111	371.7353	19.5922
orient			45	1		lo	540	360	583.8519	303.4171	15.9915
orient			135	0		hi	540	360	729.2463	338.6461	17.8482
orient			135	0		lo	540	360	711.7509	284.6199	15.0008
orient			135	1		hi	540	360	786.8102	401.4913	21.1604
orient			135	1		lo	540	360	782.7593	289.1730	15.2408
both			315	0		hi	540	360	423.2278	247.1273	13.0248
both			315	0		lo	540	360	393.7148	118.9927	6.2715
both			315	1		hi	540	360	474.6667	189.7425	10.0003
both			315	1		lo	540	360	478.3324	212.3888	11.1939
both			225	0		hi	540	360	478.5074	200.6341	10.5743
both			225	0		lo	540	360	470.6491	194.4993	10.2510
both			225	1		hi	540	360	592.6935	242.2529	12.7679
both			225	1		lo	540	360	637.7222	320.6341	16.8989
both			45	0		hi	540	360	398.2852	117.7072	6.2037
both			45	0		lo	540	360	395.5611	121.3995	6.3983
both			45	1		hi	540	360	474.1704	153.1929	8.0740
both			45	1		lo	540	360	467.9741	147.8648	7.7932
both			135	0		hi	540	360	477.7963	221.2163	11.6591
both			135	0		lo	540	360	478.2917	212.7873	11.2149
both			135	1		hi	540	360	596.3620	289.7032	15.2687
both			135	1		lo	540	360	619.0667	279.0596	14.7077

SOURCE: cue horz mirr dis vert

cue	shape	horz	orient	mirr	dis	vert	n	N	MEAN	SD	SE
orient		1		0	0	hi	540	180	615.1463	256.2544	19.1001
orient		1		0	0	lo	540	180	604.1222	238.6359	17.7869
orient		1		0	2	hi	180	180	623.0111	247.4571	18.4444
orient		1		0	2	lo	180	180	594.9444	264.3455	19.7032
orient		1		0	1	hi	180	180	613.9778	375.5562	27.9923
orient		1		0	1	lo	180	180	592.5611	242.8558	18.1014
orient		1		0	3	hi	180	180	586.3500	265.9618	19.8236
orient		1		0	3	lo	180	180	648.6778	513.1429	38.2474
orient		1		1	0	hi	540	180	664.0463	235.4236	17.5474
orient		1		1	0	lo	540	180	648.4537	201.3782	15.0098
orient		1		1	2	hi	180	180	684.9000	293.9803	21.9120
orient		1		1	2	lo	180	180	672.9444	249.9823	18.6326
orient		1		1	1	hi	180	180	659.3333	257.2958	19.1777
orient		1		1	1	lo	180	180	654.7111	264.7891	19.7362
orient		1		1	3	hi	180	180	692.3111	313.6376	23.3772
orient		1		1	3	lo	180	180	695.4556	248.7336	18.5395
orient		0		0	0	hi	540	180	579.3556	193.4232	14.4169
orient		0		0	0	lo	540	180	574.8556	211.1658	15.7394
orient		0		0	2	hi	180	180	596.0889	236.7025	17.6428
orient		0		0	2	lo	180	180	608.2611	261.8238	19.5152
orient		0		0	1	hi	180	180	584.6222	260.9995	19.4538
orient		0		0	1	lo	180	180	584.9056	247.6183	18.4564
orient		0		0	3	hi	180	180	621.7167	290.4539	21.6492
orient		0		0	3	lo	180	180	620.2833	272.6666	20.3234
orient		0		1	0	hi	540	180	663.8519	249.3963	18.5889
orient		0		1	0	lo	540	180	656.3019	250.8304	18.6958
orient		0		1	2	hi	180	180	756.3056	626.2088	46.6748
orient		0		1	2	lo	180	180	717.5444	358.0243	26.6856
orient		0		1	1	hi	180	180	648.0167	246.6102	18.3812
orient		0		1	1	lo	180	180	666.2667	278.4080	20.7513
orient		0		1	3	hi	180	180	736.8333	550.9894	41.0683
orient		0		1	3	lo	180	180	733.3944	421.9290	31.4487
both		1		0	0	hi	540	180	406.3685	117.3218	8.7446
both		1		0	0	lo	540	180	405.3593	126.9853	9.4649
both		1		0	2	hi	180	180	459.2500	212.9879	15.8752
both		1		0	2	lo	180	180	480.6889	243.7258	18.1662
both		1		0	1	hi	180	180	425.8389	180.8212	13.4776
both		1		0	1	lo	180	180	418.2500	194.1452	14.4707
both		1		0	3	hi	180	180	457.0944	157.4391	11.7348
both		1		0	3	lo	180	180	447.4222	136.7765	10.1947
both		1		1	0	hi	540	180	495.2056	180.2428	13.4345
both		1		1	0	lo	540	180	496.8722	166.3037	12.3955
both		1		1	2	hi	180	180	578.8500	212.8790	15.8671
both		1		1	2	lo	180	180	553.3000	195.1896	14.5486
both		1		1	1	hi	180	180	522.9333	221.1888	16.4864
both		1		1	1	lo	180	180	556.7278	337.6600	25.1677
both		1		1	3	hi	180	180	542.7111	226.5026	16.8825
both		1		1	3	lo	180	180	602.7556	265.3162	19.7755
both		0		0	0	hi	540	180	406.4704	131.1472	9.7751
both		0		0	0	lo	540	180	390.0463	105.3229	7.8503
both		0		0	2	hi	180	180	477.5944	206.1948	15.3689
both		0		0	2	lo	180	180	441.2333	157.7962	11.7614
both		0		0	1	hi	180	180	432.8500	312.5077	23.2929
both		0		0	1	lo	180	180	404.1056	132.9663	9.9107
both		0		0	3	hi	180	180	490.1667	240.7169	17.9420
both		0		0	3	lo	180	180	489.3278	206.1528	15.3657
both		0		1	0	hi	540	180	479.6796	154.3916	11.5077
both		0		1	0	lo	540	180	489.4130	159.2936	11.8730
both		0		1	2	hi	180	180	564.6167	268.9773	20.0484
both		0		1	2	lo	180	180	610.6722	346.7657	25.8464
both		0		1	1	hi	180	180	509.1944	257.9892	19.2294
both		0		1	1	lo	180	180	505.9111	216.2945	16.1216
both		0		1	3	hi	180	180	582.5944	287.9444	21.4621
both		0		1	3	lo	180	180	590.5389	293.8728	21.9040

FACTOR:	subj	cue	shape	horz	orient	mirr	dis	vert
LEVELS:	15	2	3	2	4	2	4	2
TYPE :	RANDOM	WITHIN	WITHIN	WITHIN	WITHIN	WITHIN	WITHIN	WITHIN

FACTOR:	DATA
LEVELS:	11520
TYPE :	DATA

SOURCE	SS	df	MS	F	p	
mean	3708779082.2605	1	3708779082.2605	347.583	0.000	***
s/	149382616.9434	14	10670186.9245			
cue	67129263.6703	1	67129263.6703	128.964	0.000	***

cs/	7287360.1046	14	520525.7218			
shape	11959253.9989	2	5979626.9995	16.277	0.000	***
ss/	10286514.8600	28	367375.5307			
cs	1171289.4681	2	585644.7341	5.189	0.012	*
css/	3160249.4172	28	112866.0506			
horz	35560.5588	1	35560.5588	0.246	0.628	
hs/	2022765.6597	14	144483.2614			
ch	19314.8417	1	19314.8417	0.399	0.538	
chs/	677866.8314	14	48419.0594			
sh	81076.3929	2	40538.1965	0.722	0.495	
shs/	1572821.2149	28	56172.1862			
csh	21885.4224	2	10942.7112	0.445	0.645	
cshs/	687923.2842	28	24568.6887			
orient	66322955.1115	3	22107651.7038	53.691	0.000	***
os/	17293741.7258	42	411755.7554			
co	6360493.8734	3	2120164.6245	19.423	0.000	***
cos/	4584508.4707	42	109154.9636			
so	532908.6720	6	88818.1120	0.663	0.680	
sos/	11255091.9565	84	133989.1900			
cso	1107457.4798	6	184576.2466	2.394	0.035	*
csos/	6476744.3750	84	77104.0997			
ho	154965.1622	3	51655.0541	1.087	0.365	
hos/	1996098.7287	42	47526.1602			
cho	84712.2028	3	28237.4009	0.899	0.450	
chos/	1318594.6956	42	31395.1118			
sho	161182.5355	6	26863.7559	0.527	0.787	
shos/	4285863.3232	84	51022.1824			
csho	99461.8953	6	16576.9826	0.280	0.945	
cshos/	4964680.0587	84	59103.3340			
mirr	24503998.7953	1	24503998.7953	29.265	0.000	***
ms/	11722264.8644	14	837304.6332			
cm	340837.0297	1	340837.0297	2.161	0.164	
cms/	2208561.3335	14	157754.3810			
sm	223688.9465	2	111844.4732	0.689	0.510	
sms/	4545301.6341	28	162332.2012			
csm	67412.0937	2	33706.0468	0.430	0.655	
csms/	2194576.5429	28	78377.7337			
hm	200205.6116	1	200205.6116	1.288	0.275	
hms/	2176314.4227	14	155451.0302			
chm	371250.9705	1	371250.9705	4.052	0.064	
chms/	1282587.9325	14	91613.4238			
shm	328467.8051	2	164233.9026	2.963	0.068	
shms/	1551996.5437	28	55428.4480			
cshm	7488.8617	2	3744.4309	0.110	0.896	
cshms/	951086.3003	28	33967.3679			

om	879583.8554	3	293194.6185	7.474	0.000	***
oms/	1647535.5054	42	39227.0358			
com	838038.4304	3	279346.1435	4.399	0.009	**
coms/	2667349.6562	42	63508.3251			
som	229382.1526	6	38230.3588	0.618	0.715	
soms/	5193798.0386	84	61830.9290			
csom	399085.3213	6	66514.2202	1.235	0.297	
csoms/	4522258.4141	84	53836.4097			
hom	40202.9052	3	13400.9684	0.386	0.764	
homs/	1458823.4147	42	34733.8908			
chom	232602.6692	3	77534.2231	1.225	0.313	
choms/	2659101.4723	42	63311.9398			
shom	235685.9536	6	39280.9923	1.049	0.400	
shoms/	3144767.6950	84	37437.7107			
cshom	102437.2768	6	17072.8795	0.391	0.883	
cshoms/	3664974.9013	84	43630.6536			
dis	7531944.7863	3	2510648.2621	32.653	0.000	***
ds/	3229304.2948	42	76888.1975			
cd	812060.2106	3	270686.7369	5.613	0.002	**
cds/	2025550.6931	42	48227.3975			
sd	633313.2737	6	105552.2123	2.048	0.068	
sds/	4329846.1805	84	51545.7879			
csd	188158.7246	6	31359.7874	1.365	0.238	
csds/	1930096.1478	84	22977.3351			
hd	788831.7490	3	262943.9163	3.804	0.017	*
hds/	2903463.1465	42	69130.0749			
chd	73186.3196	3	24395.4399	0.438	0.727	
chds/	2338126.0877	42	55669.6688			
shd	19587.2229	6	3264.5371	0.084	0.998	
shds/	3257509.0352	84	38779.8695			
cshd	899648.1335	6	149941.3556	2.641	0.021	*
cshds/	4768269.7229	84	56765.1157			
od	498118.0179	9	55346.4464	1.525	0.146	
ods/	4574029.9479	126	36301.8250			
cod	599691.2596	9	66632.3622	1.311	0.238	
cods/	6405152.0973	126	50834.5405			
sod	968250.3400	18	53791.6856	1.315	0.178	
sods/	10306257.1722	252	40897.8459			
csod	1107510.2223	18	61528.3457	1.473	0.100	
csods/	10523389.2983	252	41759.4813			
hod	711869.4164	9	79096.6018	1.996	0.045	*
hods/	4992024.2530	126	39619.2401			
chod	88186.4773	9	9798.4975	0.237	0.988	
chods/	5203370.7039	126	41296.5929			
shod	832183.0077	18	46232.3893	1.007	0.452	
shods/	11570117.5140	252	45913.1647			

cshod	1243525.3440	18	69084.7413	1.292	0.193	
cshods/	13478878.2333	252	53487.6120			
md	466500.6195	3	155500.2065	7.708	0.000	***
mds/	847260.7958	42	20172.8761			
cmd	101036.2198	3	33678.7399	0.861	0.469	
cmds/	1642502.6801	42	39107.2067			
smd	908295.8297	6	151382.6383	2.494	0.029	*
smds/	5099507.0688	84	60708.4175			
csmd	597371.2479	6	99561.8747	1.351	0.244	
csmds/	6188413.4203	84	73671.5883			
hmd	283542.7591	3	94514.2530	2.100	0.115	
hmds/	1890578.5482	42	45013.7750			
chmd	20165.8848	3	6721.9616	0.162	0.921	
chmds/	1743305.2803	42	41507.2686			
shmd	557312.8758	6	92885.4793	1.380	0.232	
shmds/	5652444.7626	84	67291.0091			
cshmd	540331.1907	6	90055.1984	2.063	0.066	
cshmds/	3666609.2634	84	43650.1103			
omd	388160.7471	9	43128.9719	1.002	0.442	
omds/	5421856.0780	126	43030.6038			
comd	269602.4806	9	29955.8312	0.763	0.650	
comds/	4944081.0256	126	39238.7383			
somd	625279.6354	18	34737.7575	0.798	0.702	
somds/	10966538.0224	252	43518.0080			
csomd	777594.6359	18	43199.7020	0.890	0.591	
csomds/	12225803.0204	252	48515.0914			
homd	586619.3496	9	65179.9277	1.350	0.218	
homds/	6083618.1733	126	48282.6839			
chomd	110310.5945	9	12256.7327	0.244	0.987	
chomds/	6325840.4909	126	50205.0833			
shomd	833842.5243	18	46324.5847	1.132	0.321	
shomds/	10312294.0426	252	40921.8018			
cshomd	382765.6258	18	21264.7570	0.567	0.921	
cshomds/	9457541.1155	252	37529.9251			
vert	2.6889	1	2.6889	0.000	0.995	
vs/	880548.5194	14	62896.3228			
cv	30063.5456	1	30063.5456	0.452	0.512	
cvs/	931528.3191	14	66537.7371			
sv	109785.4935	2	54892.7468	1.736	0.195	
svs/	885360.4011	28	31620.0143			
csv	17648.1438	2	8824.0719	0.127	0.881	
csvs/	1939777.2104	28	69277.7575			
hv	24228.5293	1	24228.5293	0.646	0.435	
hvs/	524933.6014	14	37495.2572			
chv	26610.5387	1	26610.5387	1.010	0.332	

chvs/	368678.0475	14	26334.1462			
shv	50740.7484	2	25370.3742	0.584	0.564	
shvs/	1216334.2908	28	43440.5104			
cshv	67046.7534	2	33523.3767	0.706	0.502	
cshvs/	1329333.4172	28	47476.1935			
ov	41065.6460	3	13688.5487	0.274	0.844	
ovs/	2098069.6154	42	49954.0385			
cov	236880.6900	3	78960.2300	1.669	0.188	
covs/	1987187.9420	42	47313.9986			
sov	187953.3413	6	31325.5569	0.634	0.702	
sovs/	4148940.3246	84	49392.1467			
csov	300367.4088	6	50061.2348	1.835	0.102	
csovs/	2291836.7012	84	27283.7703			
hov	189782.4205	3	63260.8068	1.735	0.174	
hovs/	1531510.7395	42	36464.5414			
chov	61530.0084	3	20510.0028	0.835	0.482	
chovs/	1031283.3216	42	24554.3648			
shov	345536.9493	6	57589.4915	1.056	0.396	
shovs/	4581994.2839	84	54547.5510			
cshov	444652.3793	6	74108.7299	1.241	0.294	
cshovs/	5016187.9062	84	59716.5227			
mv	55706.9424	1	55706.9424	0.841	0.375	
mvs/	927358.6067	14	66239.9005			
cmv	218103.2168	1	218103.2168	6.608	0.022	*
cmvs/	462062.1738	14	33004.4410			
smv	18232.7200	2	9116.3600	0.261	0.772	
smvs/	977065.1044	28	34895.1823			
csmv	88722.5116	2	44361.2558	0.878	0.427	
csmvs/	1414415.9904	28	50514.8568			
hmv	13334.3085	1	13334.3085	0.566	0.464	
hmvs/	330073.6135	14	23576.6867			
chmv	19472.2662	1	19472.2662	0.436	0.520	
chmvs/	624886.2634	14	44634.7331			
shmv	127430.0635	2	63715.0318	1.635	0.213	
shmvs/	1090856.0820	28	38959.1458			
cshmv	6977.2974	2	3488.6487	0.128	0.880	
cshmvs/	763504.7754	28	27268.0277			
omv	234347.0504	3	78115.6835	3.190	0.033	*
omvs/	1028448.1239	42	24486.8601			
comv	398709.5209	3	132903.1736	3.762	0.018	*
comvs/	1483855.2652	42	35329.8873			
somv	344097.7954	6	57349.6326	1.166	0.332	
somvs/	4131854.1259	84	49188.7396			
csomv	450264.7409	6	75044.1235	2.115	0.060	
csomvs/	2980572.5855	84	35483.0070			

homv	80597.1494	3	26865.7165	0.447	0.721
homvs/	2525227.7262	42	60124.4697		
chomv	192441.0768	3	64147.0256	1.096	0.361
chomvs/	2457945.7991	42	58522.5190		
shomv	219639.2855	6	36606.5476	0.684	0.663
shomvs/	4494347.0256	84	53504.1313		
cshomv	93576.7096	6	15596.1183	0.430	0.857
cshomvs/	3045805.3530	84	36259.5875		
dv	223225.1053	3	74408.3684	1.970	0.133
dvs/	1586194.4874	42	37766.5354		
cdv	40693.9324	3	13564.6441	0.357	0.784
cdvs/	1595800.2396	42	37995.2438		
sdv	182523.1108	6	30420.5185	0.632	0.704
sdvs/	4040727.5315	84	48103.8992		
csdv	570834.0064	6	95139.0011	1.954	0.082
csdvs/	4090862.4326	84	48700.7432		
hdv	132013.4364	3	44004.4788	0.756	0.525
hdvs/	2443959.7294	42	58189.5174		
chdv	105943.5531	3	35314.5177	0.456	0.714
chdvs/	3251601.5239	42	77419.0839		
shdv	135029.1489	6	22504.8582	0.490	0.814
shdvs/	3854346.1715	84	45885.0735		
cshdv	49928.1588	6	8321.3598	0.171	0.984
cshdvs/	4087854.3712	84	48664.9330		
odv	575907.7073	9	63989.7453	1.383	0.203
odvs/	5831358.3077	126	46280.6215		
codv	486906.9594	9	54100.7733	1.540	0.141
codvs/	4426935.8832	126	35134.4118		
sodv	994507.4457	18	55250.4137	1.466	0.103
sodvs/	9498014.1513	252	37690.5323		
csodv	718152.1125	18	39897.3396	1.121	0.332
csodvs/	8968800.1483	252	35590.4768		
hodv	493347.9851	9	54816.4428	1.123	0.351
hodvs/	6149613.8808	126	48806.4594		
chodv	419434.0253	9	46603.7806	1.518	0.148
chodvs/	3867374.1182	126	30693.4454		
shodv	1053955.9889	18	58553.1105	1.057	0.397
shodvs/	13963901.5296	252	55412.3077		
cshodv	953571.6841	18	52976.2047	1.309	0.182
cshodvs/	10198376.6021	252	40469.7484		
mdv	68873.2901	3	22957.7634	0.448	0.720
mdvs/	2149949.7438	42	51189.2796		
cmdv	83465.7009	3	27821.9003	0.570	0.638
cmdvs/	2048363.5385	42	48770.5604		
smdv	153597.7852	6	25599.6309	0.430	0.857
smdvs/	4995266.8206	84	59467.4621		
csmdv	386919.1620	6	64486.5270	1.455	0.204
csmdvs/	3721659.7947	84	44305.4737		
hmdv	40053.4086	3	13351.1362	0.335	0.800
hmdvs/	1671735.2517	42	39803.2203		
chmdv	580348.8076	3	193449.6025	3.686	0.019 *
chmdvs/	2204323.3357	42	52483.8889		
shmdv	313262.5953	6	52210.4326	0.998	0.433
shmdvs/	4396549.4862	84	52339.8748		
cshmdv	275285.2692	6	45880.8782	0.948	0.465
cshmdvs/	4063730.6152	84	48377.7454		
omdv	463863.8968	9	51540.4330	1.055	0.401
omdvs/	6155236.5478	126	48851.0837		
comdv	687657.6795	9	76406.4088	1.874	0.062
comdvs/	5137420.0929	126	40773.1753		
somdv	1055116.2884	18	58617.5716	1.298	0.189
somdvs/	11378281.5594	252	45151.9110		
csomdv	1098960.5579	18	61053.3643	1.499	0.090
csomdvs/	10267206.2666	252	40742.8820		
homdv	562897.7515	9	62544.1946	1.490	0.159
homdvs/	5289538.6846	126	41980.4658		
chomdv	285467.0800	9	31718.5644	0.564	0.825
chomdvs/	7089684.3864	126	56267.3364		
shomdv	916358.9391	18	50908.8300	1.224	0.242
shomdvs/	10483768.1377	252	41602.2545		
cshomdv	463884.1852	18	25771.3436	0.757	0.750
cshomdvs/	8584338.7566	252	34064.8363		

Appendix 3

No-Saccade and Saccade analyses from Experiment 3

This appendix contains the results from the two analyses of variance for the saccade and no-saccade trials in Experiment 3. Included for both analyses are the means from each main effect and from every interaction that was significant in either analysis ($p < .05$). Listed below are the factors used in these two analyses and the labels associated with them.

cue - type of cue presented before stimulus
- sh0 - no-image (no-shape) cue
- sh1 - image (shape) cue

dir - type of instructions given to subject
- noi - neutral instructions, no suggestion of retino or spatio results
- ret - when eyes move, suggest image be in same retinotopic location
- spt - when eyes move, suggest image be in same spatiotopic location

pm - position match
- In no-saccade trials:
  - pm1 - cue in same location as stimulus
  - pm0 - cue in different location than stimulus
- In saccade trials:
  - pm1 - cue in same retinotopic location as stimulus
  - pm0 - cue in same spatiotopic location as stimulus

hm - handedness of test stimulus
- hm1 - normal
- hm0 - mirror reversed

shape - character used for test stimulus
- numfour - the digit 4
- letterr - the letter R
- letterj - the letter J

ior - orientation of cue and test stimulus
- ior0 - 45°
- ior1 - 135°
- ior2 - 225°
- ior3 - 315°

SOURCE: dir

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
noi						4712	2400	693.1106	317.9086	6.4893
ret						4713	2400	682.8956	269.5938	5.5031
spt						4733	2400	752.6717	359.1224	7.3306

SOURCE: pm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0					7074	3600	731.3825	317.1806	5.2863
	pm1					7084	3600	687.7361	319.5622	5.3260

SOURCE: dir pm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
noi	pm0					2357	1200	719.4108	324.6932	9.3731
noi	pm1					2355	1200	666.8104	308.8782	8.9165
ret	pm0					2352	1200	709.2083	271.8613	7.8480
ret	pm1					2361	1200	656.5829	264.8166	7.6446
spt	pm0					2365	1200	765.5283	347.6228	10.0350
spt	pm1					2368	1200	739.8150	369.9633	10.6799

SOURCE: hm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0				7046	3600	754.3846	323.0097	5.3835
		hm1				7112	3600	664.7340	308.7415	5.1457

SOURCE: pm hm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0	hm0				3520	1800	782.4147	326.1335	7.6870
	pm0	hm1				3554	1800	680.3503	299.4803	7.0588
	pm1	hm0				3526	1800	726.3544	317.4795	7.4831
	pm1	hm1				3558	1800	649.1178	317.0476	7.4729

SOURCE: shape

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterj			4716	2400	712.9925	334.3623	6.8251
			letterr			4735	2400	682.7454	293.4664	5.9904
			numfour			4707	2400	732.9400	326.1262	6.6570

SOURCE: pm shape

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0		letterj			2362	1200	735.4629	336.8366	9.7236
	pm0		letterr			2363	1200	708.9529	298.9242	8.6292
	pm0		numfour			2349	1200	749.7317	313.5389	9.0511
	pm1		letterj			2354	1200	690.5221	330.4844	9.5403
	pm1		letterr			2372	1200	656.5379	285.6333	8.2455
	pm1		numfour			2358	1200	716.1483	337.5416	9.7440

SOURCE: dir pm hm shape

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
noi	pm0	hm0	letterj			393	200	771.4450	349.3835	24.7051
noi	pm0	hm0	letterr			387	200	766.8375	351.4369	24.8503
noi	pm0	hm0	numfour			393	200	773.5200	333.6009	23.5891
noi	pm0	hm1	letterj			393	200	676.8350	335.9910	23.7582
noi	pm0	hm1	letterr			395	200	641.9175	274.5405	19.4129
noi	pm0	hm1	numfour			396	200	685.9100	270.4902	19.1265
noi	pm1	hm0	letterj			385	200	714.1425	343.7821	24.3091
noi	pm1	hm0	letterr			393	200	675.0500	265.7523	18.7915
noi	pm1	hm0	numfour			389	200	752.7550	341.6092	24.1554
noi	pm1	hm1	letterj			398	200	617.1100	284.8125	20.1393
noi	pm1	hm1	letterr			395	200	589.5675	272.3944	19.2612
noi	pm1	hm1	numfour			395	200	652.2375	309.1465	21.8600
ret	pm0	hm0	letterj			389	200	749.1400	266.9141	18.8737
ret	pm0	hm0	letterr			396	200	745.2150	270.5967	19.1341
ret	pm0	hm0	numfour			384	200	777.3225	267.8234	18.9380
ret	pm0	hm1	letterj			396	200	678.4725	309.0399	21.8524
ret	pm0	hm1	letterr			396	200	634.1500	248.9236	17.6016
ret	pm0	hm1	numfour			391	200	670.9500	236.6304	16.7323
ret	pm1	hm0	letterj			391	200	700.8175	248.5423	17.5746
ret	pm1	hm0	letterr			394	200	666.7700	231.8554	16.3946
ret	pm1	hm0	numfour			391	200	704.2375	274.4752	19.4083
ret	pm1	hm1	letterj			393	200	614.5575	281.6199	19.9135
ret	pm1	hm1	letterr			396	200	590.2825	230.4234	16.2934
ret	pm1	hm1	numfour			396	200	662.8325	297.7786	21.0561
spt	pm0	hm0	letterj			396	200	836.6700	386.4273	27.3245
spt	pm0	hm0	letterr			393	200	786.7525	324.6733	22.9579
spt	pm0	hm0	numfour			389	200	834.8300	353.5969	25.0031
spt	pm0	hm1	letterj			395	200	700.2150	335.8863	23.7507
spt	pm0	hm1	letterr			396	200	678.8450	277.6280	19.6313
spt	pm0	hm1	numfour			396	200	755.8575	368.9448	26.0883
spt	pm1	hm0	letterj			392	200	793.1050	410.3848	29.0186
spt	pm1	hm0	letterr			397	200	740.5775	331.4218	23.4351
spt	pm1	hm0	numfour			394	200	789.7350	345.8778	24.4573
spt	pm1	hm1	letterj			395	200	703.4000	355.8576	25.1629
spt	pm1	hm1	letterr			397	200	676.9800	336.4010	23.7871
spt	pm1	hm1	numfour			393	200	735.0925	419.8878	29.6906

SOURCE: cue

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
				shc0		7031	3600	786.6397	343.2104	5.7202
				shc1		7127	3600	632.4789	272.0236	4.5337

SOURCE: pm cue

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0			shc0		3520	1800	794.1172	334.4714	7.8836
	pm0			shc1		3554	1800	668.6478	285.5103	6.7295
	pm1			shc0		3511	1800	779.1622	351.6663	8.2889
	pm1			shc1		3573	1800	596.3100	252.7862	5.9582

SOURCE: hm cue

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0		shc0		3495	1800	819.5861	341.9949	8.0609
		hm0		shc1		3551	1800	689.1831	288.5496	6.8012
		hm1		shc0		3536	1800	753.6933	341.3497	8.0457
		hm1		shc1		3576	1800	575.7747	241.5361	5.6931

SOURCE: ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
					ior2	3495	1800	809.8122	345.3022	8.1388
					ior1	3513	1800	801.5717	336.9603	7.9422
					ior3	3577	1800	614.2339	255.4512	6.0210
					ior0	3573	1800	612.6194	269.0965	6.3427

SOURCE: hm ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0			ior2	1720	900	874.6789	363.5989	12.1200
		hm0			ior1	1753	900	823.5556	317.9797	10.5993
		hm0			ior3	1787	900	660.2261	263.6992	8.7900
		hm0			ior0	1786	900	659.0778	278.5513	9.2850
		hm1			ior2	1775	900	744.9456	313.0030	10.4334
		hm1			ior1	1760	900	779.5878	353.7401	11.7913
		hm1			ior3	1790	900	568.2417	238.3500	7.9450
		hm1			ior0	1787	900	566.1611	250.9862	8.3662

SOURCE: shape ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterj		ior2	1158	600	833.0942	368.1009	15.0277
			letterj		ior1	1175	600	805.6900	343.1991	14.0110
			letterj		ior3	1194	600	604.2542	251.0371	10.2485
			letterj		ior0	1189	600	608.9317	292.7504	11.9515
			letterr		ior2	1170	600	780.7250	322.7403	13.1758
			letterr		ior1	1179	600	771.1617	311.1276	12.7017
			letterr		ior3	1193	600	602.0667	251.2202	10.2560
			letterr		ior0	1193	600	577.0283	213.7449	8.7261
			numfour		ior2	1167	600	815.6175	342.0746	13.9651
			numfour		ior1	1159	600	827.8633	353.2480	14.4213
			numfour		ior3	1190	600	636.3808	262.8941	10.7326
			numfour		ior0	1191	600	651.8983	288.5534	11.7801

SOURCE: hm shape ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE

dir	pm	hm	shape	ior	n	N	MEAN	SD	SE
		hm0	letterj	ior2	564	300	927.4617	397.0577	22.9241
		hm0	letterj	ior1	590	300	809.9017	305.0193	17.6103
		hm0	letterj	ior3	597	300	657.9267	269.9858	15.5876
		hm0	letterj	ior0	595	300	648.2567	302.1330	17.4437
		hm0	letterr	ior2	579	300	836.5050	341.3128	19.7057
		hm0	letterr	ior1	589	300	805.6933	305.3951	17.6320
		hm0	letterr	ior3	596	300	649.7883	262.7021	15.1671
		hm0	letterr	ior0	596	300	628.8150	228.7651	13.2078
		hm0	numfour	ior2	577	300	860.0700	344.7841	19.9061
		hm0	numfour	ior1	574	300	855.0717	340.8854	19.6810
		hm0	numfour	ior3	594	300	672.9633	258.6404	14.9326
		hm0	numfour	ior0	595	300	700.1617	294.8622	17.0239
		hm1	letterj	ior2	594	300	738.7267	309.7174	17.8815
		hm1	letterj	ior1	585	300	801.4783	378.0116	21.8245
		hm1	letterj	ior3	597	300	550.5817	218.1215	12.5933
		hm1	letterj	ior0	594	300	569.6067	278.0371	16.0525
		hm1	letterr	ior2	591	300	724.9450	293.1433	16.9246
		hm1	letterr	ior1	590	300	736.6300	313.4733	18.0984
		hm1	letterr	ior3	597	300	554.3450	229.8954	13.2730
		hm1	letterr	ior0	597	300	525.2417	183.8789	10.6163
		hm1	numfour	ior2	590	300	771.1650	334.0361	19.2856
		hm1	numfour	ior1	585	300	800.6550	363.7269	20.9998
		hm1	numfour	ior3	596	300	599.7983	262.4450	15.1523
		hm1	numfour	ior0	596	300	603.6350	274.2017	15.8310

SOURCE: cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
				shc0	ior2	1728	900	902.7822	360.4994	12.0166
				shc0	ior1	1740	900	897.3694	348.1744	11.6058
				shc0	ior3	1786	900	676.6478	277.8986	9.2633
				shc0	ior0	1777	900	669.7594	302.6335	10.0878
				shc1	ior2	1767	900	716.8422	302.2150	10.0738
				shc1	ior1	1773	900	705.7739	295.9908	9.8664
				shc1	ior3	1791	900	551.8200	213.4385	7.1146
				shc1	ior0	1796	900	555.4794	216.2919	7.2097

SOURCE: pm cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0			shc0	ior2	867	450	900.4811	351.3627	16.5634
	pm0			shc0	ior1	869	450	897.7256	337.0056	15.8866
	pm0			shc0	ior3	894	450	694.9833	282.3739	13.3112
	pm0			shc0	ior0	890	450	683.2789	295.3125	13.9212
	pm0			shc1	ior2	882	450	765.7989	314.9113	14.8451
	pm0			shc1	ior1	881	450	749.9544	294.4249	13.8793
	pm0			shc1	ior3	892	450	576.9211	237.6636	11.2036
	pm0			shc1	ior0	899	450	581.9167	228.5032	10.7717
	pm1			shc0	ior2	861	450	905.0833	369.7874	17.4319
	pm1			shc0	ior1	871	450	897.0133	359.3713	16.9409
	pm1			shc0	ior3	892	450	658.3122	272.4303	12.8425
	pm1			shc0	ior0	887	450	656.2400	309.5194	14.5909
	pm1			shc1	ior2	885	450	667.8856	280.8876	13.2412
	pm1			shc1	ior1	892	450	661.5933	291.2347	13.7289
	pm1			shc1	ior3	899	450	526.7189	182.9386	8.6238
	pm1			shc1	ior0	897	450	529.0422	200.1346	9.4344

SOURCE: hm cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0		shc0	ior2	846	450	957.9756	383.3474	18.0712
		hm0		shc0	ior1	869	450	888.4211	316.9134	14.9394
		hm0		shc0	ior3	891	450	719.9411	277.2984	13.0720
		hm0		shc0	ior0	889	450	712.0067	314.3983	14.8209
		hm0		shc1	ior2	874	450	791.3822	322.2422	15.1906
		hm0		shc1	ior1	884	450	758.6900	305.9075	14.4206
		hm0		shc1	ior3	896	450	600.5111	234.9200	11.0742
		hm0		shc1	ior0	897	450	606.1489	225.5942	10.6346
		hm1		shc0	ior2	882	450	847.5889	327.3342	15.4307
		hm1		shc0	ior1	871	450	906.3178	376.9963	17.7718
		hm1		shc0	ior3	895	450	633.3544	271.9850	12.8215
		hm1		shc0	ior0	888	450	627.5122	284.5245	13.4126
		hm1		shc1	ior2	893	450	642.3022	260.5647	12.2831
		hm1		shc1	ior1	889	450	652.8578	276.0871	13.0149
		hm1		shc1	ior3	895	450	503.1289	176.8441	8.3365
		hm1		shc1	ior0	899	450	504.8100	193.9834	9.1445

SOURCE: shape cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterj	shc0	ior2	573	300	923.2817	384.4908	22.1986
			letterj	shc0	ior1	582	300	917.8500	356.5612	20.5861
			letterj	shc0	ior3	595	300	653.7333	257.4598	14.8644
			letterj	shc0	ior0	590	300	670.2167	335.1776	19.3515
			letterj	shc1	ior2	585	300	742.9067	327.5585	18.9116
			letterj	shc1	ior1	593	300	693.5300	289.1113	16.6918
			letterj	shc1	ior3	599	300	554.7750	234.6311	13.5464
			letterj	shc1	ior0	599	300	547.6467	227.6212	13.1417
			letterr	shc0	ior2	580	300	881.6850	328.9999	18.9948
			letterr	shc0	ior1	587	300	852.1500	308.1807	17.7928
			letterr	shc0	ior3	596	300	670.2083	275.0674	15.8810
			letterr	shc0	ior0	595	300	619.1367	219.9017	12.6960
			letterr	shc1	ior2	590	300	679.7650	282.8004	16.3275
			letterr	shc1	ior1	592	300	690.1733	292.8943	16.9103
			letterr	shc1	ior3	597	300	533.9250	203.6039	11.7551
			letterr	shc1	ior0	598	300	534.9200	199.0269	11.4908
			numfour	shc0	ior2	575	300	903.3800	365.7952	21.1192
			numfour	shc0	ior1	571	300	922.1083	373.2149	21.5476
			numfour	shc0	ior3	595	300	706.0017	298.0249	17.2065
			numfour	shc0	ior0	592	300	719.9250	331.0235	19.1116
			numfour	shc1	ior2	592	300	727.8550	291.8207	16.8483
			numfour	shc1	ior1	588	300	733.6183	304.7502	17.5948
			numfour	shc1	ior3	595	300	566.7600	199.7809	11.5344
			numfour	shc1	ior0	599	300	583.8717	218.9562	12.6414

FACTOR:	subj	dir	pm	hm	shape	cue	ior	time
LEVELS:	75	3	2	2	3	2	4	7200
TYPE :	RANDOM	BETWEEN	WITHIN	WITHIN	WITHIN	WITHIN	WITHIN	DATA

SOURCE	SS	df	MS	F	p
dir	6816447.9201	2	3408223.9600	0.974	0.382
s/d	251904217.9596	72	3498669.6939		
pm	3429013.0735	1	3429013.0735	74.479	0.000 ***
ps/d	3314866.6692	72	46039.8148		
dp	289435.2209	2	144717.6105	3.143	0.049 *
ps/d	3314866.6692	72	46039.8148		
hm	14466999.8006	1	14466999.8006	128.888	0.000 ***
hs/d	8081631.6079	72	112244.8834		
dh	80991.2738	2	40495.6369	0.361	0.698
hs/d	8081631.6079	72	112244.8834		
ph	277388.3472	1	277388.3472	6.347	0.014 *
phs/d	3146556.8858	72	43702.1790		
dph	71679.0847	2	35839.5423	0.820	0.444
phs/d	3146556.8858	72	43702.1790		
shape	3065828.0019	2	1532914.0010	14.939	0.000 ***
ss/d	14775712.5310	144	102609.1148		
ds	48991.4514	4	12247.8628	0.119	0.975
ss/d	14775712.5310	144	102609.1148		
ps	107897.5286	2	53948.7643	1.183	0.309
pss/d	6569126.9315	144	45618.9370		
dps	166747.7639	4	41686.9410	0.914	0.458
pss/d	6569126.9315	144	45618.9370		

hs	117138.4478	2	58569.2239	1.150	0.319	
hss/d	7331230.6140	144	50911.3237			
dhs	157053.7247	4	39263.4312	0.771	0.546	
hss/d	7331230.6140	144	50911.3237			
phs	66977.2853	2	33488.6426	1.041	0.356	
phss/d	4633971.6910	144	32180.3590			
dphs	190364.3622	4	47591.0906	1.479	0.212	
phss/d	4633971.6910	144	32180.3590			
cue	42778012.5613	1	42778012.5613	170.840	0.000	***
cs/d	18028714.0396	72	250398.8061			
dc	525406.9877	2	262703.4939	1.049	0.356	
cs/d	18028714.0396	72	250398.8061			
pc	1481752.4335	1	1481752.4335	33.663	0.000	***
pcs/d	3169231.9192	72	44017.1100			
dpc	35059.7047	2	17529.8523	0.398	0.673	
pcs/d	3169231.9192	72	44017.1100			
hc	1015977.6089	1	1015977.6089	19.813	0.000	***
hcs/d	3692032.7813	72	51278.2331			
dhc	36662.4692	2	18331.2346	0.357	0.701	
hcs/d	3692032.7813	72	51278.2331			
phc	11643.3800	1	11643.3800	0.210	0.648	
phcs/d	3983350.5358	72	55324.3130			
dphc	84367.0790	2	42183.5395	0.762	0.470	
phcs/d	3983350.5358	72	55324.3130			
sc	61702.5633	2	30851.2817	0.653	0.522	
scs/d	6800637.1323	144	47226.6468			
dsc	372521.7158	4	93130.4290	1.972	0.102	
scs/d	6800637.1323	144	47226.6468			
psc	3511.7853	2	1755.8926	0.050	0.951	
pscs/d	5035829.6602	144	34971.0393			
dpsc	301185.2472	4	75296.3118	2.153	0.077	
pscs/d	5035829.6602	144	34971.0393			
hsc	109377.7019	2	54688.8510	1.577	0.210	
hscs/d	4994469.7994	144	34683.8181			
dhsc	105009.2956	4	26252.3239	0.757	0.555	
hscs/d	4994469.7994	144	34683.8181			
phsc	58260.6325	2	29130.3162	0.996	0.372	
phscs/d	4212182.1873	144	29251.2652			
dphsc	171506.0292	4	42876.5073	1.466	0.216	
phscs/d	4212182.1873	144	29251.2652			
ior	66602148.5382	3	22200716.1794	253.960	0.000	***
is/d	18882294.1338	216	87418.0284			
di	689088.9583	6	114848.1597	1.314	0.252	
is/d	18882294.1338	216	87418.0284			
pi	10577.5704	3	3525.8568	0.094	0.963	

pis/d	8065587.4925	216	37340.6828			
dpi	311123.3485	6	51853.8914	1.389	0.220	
pis/d	8065587.4925	216	37340.6828			
hi	1669346.9006	3	556448.9669	9.228	0.000	***
his/d	13024916.3837	216	60300.5388			
dhi	438514.3251	6	73085.7208	1.212	0.301	
his/d	13024916.3837	216	60300.5388			
phi	157344.9672	3	52448.3224	1.534	0.207	
phis/d	7382879.3408	216	34179.9969			
dphi	47912.8742	6	7985.4790	0.234	0.965	
phis/d	7382879.3408	216	34179.9969			
si	903819.0964	6	150636.5161	2.571	0.019	*
sis/d	25310164.4206	432	58588.3436			
dsi	565051.7903	12	47087.6492	0.804	0.647	
sis/d	25310164.4206	432	58588.3436			
psi	40591.2825	6	6765.2137	0.193	0.979	
psis/d	15147582.9019	432	35063.8493			
dpsi	116663.3417	12	9721.9451	0.277	0.993	
psis/d	15147582.9019	432	35063.8493			
hsi	1144813.0111	6	190802.1685	4.957	0.000	***
hsis/d	16629306.3944	432	38493.7648			
dhsi	459995.7664	12	38332.9805	0.996	0.452	
hsis/d	16629306.3944	432	38493.7648			
phsi	301419.9453	6	50236.6575	1.367	0.227	
phsis/d	15880682.5923	432	36760.8393			
dphsi	248086.3739	12	20673.8645	0.562	0.872	
phsis/d	15880682.5923	432	36760.8393			
ci	2187982.2949	3	729327.4316	16.239	0.000	***
cis/d	9700955.8654	216	44911.8327			
dci	141931.7928	6	23655.2988	0.527	0.788	
cis/d	9700955.8654	216	44911.8327			
pci	660510.1138	3	220170.0379	4.288	0.006	**
pcis/d	11090121.1008	216	51343.1532			
dpci	153368.6448	6	25561.4408	0.498	0.810	
pcis/d	11090121.1008	216	51343.1532			
hci	919730.1644	3	306576.7215	6.959	0.000	***
hcis/d	9515966.8988	216	44055.4023			
dhci	40085.1608	6	6680.8601	0.152	0.989	
hcis/d	9515966.8988	216	44055.4023			
phci	29224.4911	3	9741.4970	0.254	0.859	
phcis/d	8291213.0525	216	38385.2456			
dphci	169660.2533	6	28276.7089	0.737	0.621	
phcis/d	8291213.0525	216	38385.2456			
sci	659413.2006	6	109902.2001	2.877	0.009	**
scis/d	16500840.0327	432	38196.3890			

dsci	366440.3136	12	30536.6928	0.799	0.651
scis/d	16500840.0327	432	38196.3890		
psci	290426.1858	6	48404.3643	1.232	0.289
pscis/d	16975898.5898	432	39296.0616		
dpsci	143753.8650	12	11979.4888	0.305	0.988
pscis/d	16975898.5898	432	39296.0616		
hsci	253836.9714	6	42306.1619	1.052	0.391
hscis/d	17372880.2856	432	40215.0007		
dhsci	315260.4878	12	26271.7073	0.653	0.796
hscis/d	17372880.2856	432	40215.0007		
phsci	133188.3381	6	22198.0563	0.579	0.747
phscis/d	16559596.8694	432	38332.4002		
dphsci	350208.0269	12	29184.0022	0.761	0.690
phscis/d	16559596.8694	432	38332.4002		

Experiment 3 Saccade analysis   Fri May 12 14:26:46 1989   1

SOURCE: dir

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
noi						4725	2400	672.0321	311.8639	6.3659
ret						4735	2400	669.3281	265.8011	5.4256
spt						4738	2400	728.5356	346.0600	7.0639

SOURCE: pm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0					7086	3600	697.6137	320.2527	5.3375
	pm1					7112	3600	682.3168	300.9368	5.0156

SOURCE: dir pm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
noi	pm0					2358	1200	679.6700	324.5563	9.3691
noi	pm1					2367	1200	664.3942	298.5728	8.6191
ret	pm0					2366	1200	682.8933	279.7417	8.0754
ret	pm1					2369	1200	655.7629	250.4708	7.2305
spt	pm0					2362	1200	730.2779	350.2245	10.1101
spt	pm1					2376	1200	726.7933	341.9818	9.8722

SOURCE: hm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0				7074	3600	732.4203	313.3561	5.2226
		hm1				7124	3600	647.5103	302.3969	5.0399

SOURCE: pm hm

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0	hm0				3526	1800	737.3083	326.9353	7.7059
	pm0	hm1				3560	1800	657.9192	308.4490	7.2702
	pm1	hm0				3548	1800	727.5322	299.1723	7.0516
	pm1	hm1				3564	1800	637.1014	295.9409	6.9754

SOURCE: shape

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterr			4743	2400	670.7369	300.3422	6.1307
			numfour			4722	2400	707.9765	315.5386	6.4409
			letterj			4733	2400	691.1825	315.3362	6.4368

SOURCE: pm shape

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0		letterr			2368	1200	678.7133	312.8720	9.0318
	pm0		numfour			2358	1200	723.0746	326.6382	9.4292
	pm0		letterj			2360	1200	691.0533	319.7275	9.2297
	pm1		letterr			2375	1200	662.7604	287.1758	8.2901
	pm1		numfour			2364	1200	692.8783	303.4196	8.7590
	pm1		letterj			2373	1200	691.3117	311.0163	8.9783

SOURCE: dir pm hm shape

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
noi	pm0	hm0	letterr			392	200	726.8425	326.6485	23.0975
noi	pm0	hm0	numfour			394	200	738.1625	347.9377	24.6029
noi	pm0	hm0	letterj			389	200	719.6025	360.6732	25.5034
noi	pm0	hm1	letterr			391	200	597.1200	275.5192	19.4821
noi	pm0	hm1	numfour			395	200	657.2925	305.6626	21.6136
noi	pm0	hm1	letterj			397	200	639.0000	301.9770	21.3530
noi	pm1	hm0	letterr			393	200	682.7675	277.5202	19.6236
noi	pm1	hm0	numfour			392	200	740.4325	317.4737	22.4488
noi	pm1	hm0	letterj			396	200	709.0525	306.2537	21.6554
noi	pm1	hm1	letterr			397	200	612.4075	295.7093	20.9098
noi	pm1	hm1	numfour			391	200	621.4825	271.1992	19.1767
noi	pm1	hm1	letterj			398	200	620.2225	299.7342	21.1944
ret	pm0	hm0	letterr			394	200	684.2500	252.7561	17.8726
ret	pm0	hm0	numfour			392	200	750.2175	299.8585	21.2032
ret	pm0	hm0	letterj			392	200	717.0325	279.2794	19.7480
ret	pm0	hm1	letterr			396	200	646.0300	286.0591	20.2274
ret	pm0	hm1	numfour			395	200	671.4750	275.3652	19.4713
ret	pm0	hm1	letterj			397	200	628.3550	268.0122	18.9513
ret	pm1	hm0	letterr			397	200	674.5125	235.8494	16.6771
ret	pm1	hm0	numfour			390	200	702.2700	247.8020	17.5222
ret	pm1	hm0	letterj			393	200	711.0750	250.6585	17.7242
ret	pm1	hm1	letterr			397	200	593.4400	219.8027	15.5424
ret	pm1	hm1	numfour			396	200	625.7500	257.7417	18.2251
ret	pm1	hm1	letterj			396	200	627.5300	268.6512	18.9965
spt	pm0	hm0	letterr			398	200	735.8425	347.3097	24.5585
spt	pm0	hm0	numfour			387	200	812.6100	368.4685	26.0547
spt	pm0	hm0	letterj			388	200	751.2150	332.4310	23.5064
spt	pm0	hm1	letterr			397	200	682.1950	356.9699	25.2416
spt	pm0	hm1	numfour			395	200	708.6900	332.5302	23.5134
spt	pm0	hm1	letterj			397	200	691.1150	350.0001	24.7487
spt	pm1	hm0	letterr			395	200	763.8650	340.1242	24.0504
spt	pm1	hm0	numfour			397	200	779.3500	339.4950	24.0059
spt	pm1	hm0	letterj			395	200	784.4650	336.4353	23.7896
spt	pm1	hm1	letterr			396	200	649.5700	307.3116	21.7302
spt	pm1	hm1	numfour			398	200	687.9850	343.0884	24.2600
spt	pm1	hm1	letterj			395	200	695.5250	363.8380	25.7272

SOURCE: cue

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
				shc1		7140	3600	614.1742	262.5883	4.3765
				shc0		7058	3600	765.7564	335.8532	5.5976

SOURCE: pm cue

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0			shc1		3567	1800	627.3864	274.4898	6.4698
	pm0			shc0		3519	1800	767.8411	346.3620	8.1638
	pm1			shc1		3573	1800	600.9619	249.4986	5.8807
	pm1			shc0		3539	1800	763.6717	325.0878	7.6624

SOURCE: hm cue

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0		shc1		3559	1800	660.5600	268.3546	6.3252
		hm0		shc0		3515	1800	804.2806	337.7734	7.9614
		hm1		shc1		3581	1800	567.7883	248.2412	5.8511
		hm1		shc0		3543	1800	727.2322	329.5401	7.7673

SOURCE: ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
					ior2	3517	1800	786.6006	333.9808	7.8720
					ior1	3527	1800	774.8261	326.0146	7.6842
					ior0	3577	1800	596.8236	261.4928	6.1634
					ior3	3577	1800	601.6108	259.5068	6.1166

SOURCE: hm ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0			ior2	1746	900	845.0694	341.9370	11.3979
		hm0			ior1	1759	900	806.4350	320.5983	10.6866
		hm0			ior0	1784	900	635.0028	270.6973	9.0232
		hm0			ior3	1785	900	643.1739	253.8735	8.4625
		hm1			ior2	1771	900	728.1317	315.3485	10.5116
		hm1			ior1	1768	900	743.2172	328.4897	10.9497
		hm1			ior0	1793	900	558.6444	246.2467	8.2082
		hm1			ior3	1792	900	560.0478	258.5574	8.6186

SOURCE: shape ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterr		ior2	1185	600	765.3517	326.9453	13.3475
			letterr		ior1	1176	600	757.5892	324.4167	13.2443
			letterr		ior0	1192	600	564.9400	227.2479	9.2774
			letterr		ior3	1190	600	595.0667	253.0267	10.3298
			numfour		ior2	1169	600	790.8542	340.1622	13.8871
			numfour		ior1	1170	600	786.9892	324.1061	13.2316
			numfour		ior0	1189	600	629.0242	273.6824	11.1730
			numfour		ior3	1194	600	625.0383	277.1862	11.3161
			letterj		ior2	1163	600	803.5958	334.1237	13.6405
			letterj		ior1	1181	600	779.9000	329.3157	13.4443
			letterj		ior0	1196	600	596.5067	277.0616	11.3110

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterj		ior3	1193	600	584.7275	246.0149	10.0435

SOURCE: hm shape ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0	letterr		ior2	594	300	808.4050	327.9080	18.9318
		hm0	letterr		ior1	585	300	801.1883	337.8669	19.5068
		hm0	letterr		ior0	596	300	598.3700	219.6813	12.6833
		hm0	letterr		ior3	594	300	637.4233	240.1327	13.8641
		hm0	numfour		ior2	579	300	847.9200	351.4824	20.2928
		hm0	numfour		ior1	585	300	819.5567	319.2585	18.4324
		hm0	numfour		ior0	591	300	679.6683	295.3824	17.0539
		hm0	numfour		ior3	597	300	660.2167	285.3897	16.4770
		hm0	letterj		ior2	573	300	870.8833	343.4781	19.8307
		hm0	letterj		ior1	589	300	798.5600	304.4581	17.5779
		hm0	letterj		ior0	597	300	626.9700	285.3030	16.4720
		hm0	letterj		ior3	594	300	623.8817	231.6022	13.3716
		hm1	letterr		ior2	591	300	722.2983	320.7815	18.5203
		hm1	letterr		ior1	591	300	713.9900	304.7554	17.5951
		hm1	letterr		ior0	596	300	531.5100	230.1162	13.2858
		hm1	letterr		ior3	596	300	552.7100	258.8345	14.9438
		hm1	numfour		ior2	590	300	733.7883	318.9561	18.4149
		hm1	numfour		ior1	585	300	754.4217	326.1695	18.8314
		hm1	numfour		ior0	598	300	578.3800	240.1189	13.8633
		hm1	numfour		ior3	597	300	581.8600	262.1695	15.1364
		hm1	letterj		ior2	590	300	728.3083	307.0816	17.7294
		hm1	letterj		ior1	592	300	761.2400	351.9473	20.3197
		hm1	letterj		ior0	599	300	566.0433	265.5616	15.3322
		hm1	letterj		ior3	599	300	545.5733	254.0339	14.6667

SOURCE: cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
				shc1	ior2	1773	900	699.5922	295.2448	9.8415
				shc1	ior1	1777	900	681.0983	280.7210	9.3574
				shc1	ior0	1793	900	534.4372	199.2566	6.6419
				shc1	ior3	1797	900	541.5689	216.6401	7.2213
				shc0	ior2	1744	900	873.6089	347.6826	11.5894
				shc0	ior1	1750	900	868.5539	341.0214	11.3674
				shc0	ior0	1784	900	659.2100	298.8931	9.9631
				shc0	ior3	1780	900	661.6528	283.9216	9.4641

SOURCE: pm cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
	pm0			shc1	ior2	884	450	717.6289	312.2743	14.7208
	pm0			shc1	ior1	888	450	698.8300	297.1689	14.0087
	pm0			shc1	ior0	897	450	543.1600	208.5455	9.8309
	pm0			shc1	ior3	898	450	549.9267	214.8618	10.1287
	pm0			shc0	ior2	866	450	884.4156	358.2176	16.8865
	pm0			shc0	ior1	876	450	862.8867	352.3470	16.6098
	pm0			shc0	ior0	890	450	658.5856	316.6315	14.9262
	pm0			shc0	ior3	887	450	665.4767	287.7596	13.5651
	pm1			shc1	ior2	889	450	681.5556	276.3436	13.0270
	pm1			shc1	ior1	889	450	663.3667	262.3824	12.3688
	pm1			shc1	ior0	896	450	525.7144	189.3438	8.9258
	pm1			shc1	ior3	899	450	533.2111	218.3226	10.2918
	pm1			shc0	ior2	878	450	862.8022	336.8704	15.8802
	pm1			shc0	ior1	874	450	874.2211	329.6019	15.5376
	pm1			shc0	ior0	894	450	659.8344	280.3869	13.2176
	pm1			shc0	ior3	893	450	657.8289	280.2992	13.2134

SOURCE: hm cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
		hm0		shc1	ior2	880	450	767.6256	296.8899	13.9955
		hm0		shc1	ior1	887	450	730.8922	294.2118	13.8693
		hm0		shc1	ior0	895	450	562.7878	186.1764	8.7764
		hm0		shc1	ior3	897	450	580.9344	216.3119	10.1970
		hm0		shc0	ior2	866	450	922.5133	365.9738	17.2522
		hm0		shc0	ior1	872	450	881.9778	328.3231	15.4773
		hm0		shc0	ior0	889	450	707.2178	318.7513	15.0261
		hm0		shc0	ior3	888	450	705.4133	272.9313	12.8661
		hm1		shc1	ior2	893	450	631.5589	277.6901	13.0904
		hm1		shc1	ior1	890	450	631.3044	257.3978	12.1338
		hm1		shc1	ior0	898	450	506.0867	207.8992	9.8005
		hm1		shc1	ior3	900	450	502.2033	209.9365	9.8965
		hm1		shc0	ior2	878	450	824.7044	321.4107	15.1514
		hm1		shc0	ior1	878	450	855.1300	353.1189	16.6462
		hm1		shc0	ior0	895	450	611.2022	269.5383	12.7062
		hm1		shc0	ior3	892	450	617.8922	288.2231	13.5870

SOURCE: shape cue ior

dir	pm	hm	shape	cue	ior	n	N	MEAN	SD	SE
			letterr	shc1	ior2	597	300	675.8783	279.8344	16.1562
			letterr	shc1	ior1	594	300	676.3117	294.6022	17.0089
			letterr	shc1	ior0	597	300	518.8300	193.6409	11.1799
			letterr	shc1	ior3	599	300	529.9783	226.2474	13.0624
			letterr	shc0	ior2	588	300	854.8250	346.0812	19.9810
			letterr	shc0	ior1	582	300	838.8667	332.8629	19.2178
			letterr	shc0	ior0	595	300	611.0500	248.3801	14.3402
			letterr	shc0	ior3	591	300	660.1550	261.8587	15.1184
			numfour	shc1	ior2	590	300	703.1467	303.1435	17.5020
			numfour	shc1	ior1	589	300	691.6817	257.8007	14.8841
			numfour	shc1	ior0	597	300	554.7950	188.5891	10.8882
			numfour	shc1	ior3	600	300	569.8167	220.9304	12.7554
			numfour	shc0	ior2	579	300	878.5617	352.8102	20.3695
			numfour	shc0	ior1	581	300	882.2967	354.6151	20.4737
			numfour	shc0	ior0	592	300	703.2533	321.6085	18.5681
			numfour	shc0	ior3	594	300	680.2600	314.6297	18.1652
			letterj	shc1	ior2	586	300	719.7517	301.5022	17.4072
			letterj	shc1	ior1	594	300	675.3017	288.9970	16.6852
			letterj	shc1	ior0	599	300	529.6867	213.6110	12.3328
			letterj	shc1	ior3	598	300	524.9117	199.7519	11.5327
			letterj	shc0	ior2	577	300	887.4400	344.4421	19.8864
			letterj	shc0	ior1	587	300	884.4983	334.3446	19.3034
			letterj	shc0	ior0	597	300	663.3267	314.9502	18.1837
			letterj	shc0	ior3	595	300	644.5433	272.3389	15.7235

FACTOR:	subj	dir	pm	hm	shape	cue	ior	time
LEVELS:	75	3	2	2	3	2	4	7200
TYPE :	RANDOM	BETWEEN	WITHIN	WITHIN	WITHIN	WITHIN	WITHIN	DATA

SOURCE	SS	df	MS	F	p	
dir	5364391.7342	2	2682195.8671	0.772	0.466	
s/d	250188803.3613	72	3474844.4911			
pm	421193.7168	1	421193.7168	7.661	0.007	**
ps/d	3958517.9237	72	54979.4156			
dp	167738.0313	2	83869.0157	1.525	0.224	
ps/d	3958517.9237	72	54979.4156			
hm	12977474.5800	1	12977474.5800	92.530	0.000	***
hs/d	10098148.1796	72	140252.0580			
dh	125366.5581	2	62683.2791	0.447	0.641	
hs/d	10098148.1796	72	140252.0580			
ph	54863.2813	1	54863.2813	2.332	0.131	
phs/d	1693867.7329	72	23525.9407			
dph	67621.9702	2	33810.9851	1.437	0.244	
phs/d	1693867.7329	72	23525.9407			
shape	1669477.7480	2	834738.8740	8.010	0.001	***
ss/d	15007065.9875	144	104215.7360			
ds	7750.6603	4	1937.6651	0.019	0.999	

ss/d	15007065.9875	144	104215.7360			
ps	278631.7634	2	139315.8817	3.514	0.032	*
pss/d	5708359.0275	144	39641.3821			
dps	125971.0216	4	31492.7554	0.794	0.531	
pss/d	5708359.0275	144	39641.3821			
hs	41930.6515	2	20965.3257	0.485	0.617	
hss/d	6226778.6742	144	43241.5186			
dhs	116227.2785	4	29056.8196	0.672	0.612	
hss/d	6226778.6742	144	43241.5186			
phs	3652.8794	2	1826.4397	0.048	0.953	
phss/d	5520359.3133	144	38335.8286			
dphs	452701.6823	4	113175.4206	2.952	0.022	*
phss/d	5520359.3133	144	38335.8286			
cue	41358906.1689	1	41358906.1689	167.393	0.000	***
cs/d	17789532.8271	72	247076.8448			
dc	87661.8009	2	43830.9005	0.177	0.838	
cs/d	17789532.8271	72	247076.8448			
pc	222878.2613	1	222878.2613	5.888	0.018	*
pcs/d	2725458.9546	72	37853.5966			
dpc	12296.3102	2	6148.1551	0.162	0.850	
pcs/d	2725458.9546	72	37853.5966			
hc	111250.4450	1	111250.4450	2.649	0.108	
hcs/d	3024336.6329	72	42004.6755			
dhc	38895.7815	2	19447.8907	0.463	0.631	
hcs/d	3024336.6329	72	42004.6755			
phc	15129.3012	1	15129.3012	0.353	0.554	
phcs/d	3089046.9579	72	42903.4300			
dphc	100733.6419	2	50366.8209	1.174	0.315	
phcs/d	3089046.9579	72	42903.4300			
sc	101781.6892	2	50890.8446	1.416	0.246	
scs/d	5176148.0542	144	35945.4726			
dsc	69891.9753	4	17472.9938	0.486	0.746	
scs/d	5176148.0542	144	35945.4726			
psc	17282.1702	2	8641.0851	0.314	0.731	
pscs/d	3959768.3192	144	27498.3911			
dpsc	208553.5002	4	52138.3751	1.896	0.114	
pscs/d	3959768.3192	144	27498.3911			
hsc	82891.5944	2	41445.7972	1.602	0.205	
hscs/d	3725980.8583	144	25874.8671			
dhsc	62993.7660	4	15748.4415	0.609	0.657	
hscs/d	3725980.8583	144	25874.8671			
phsc	16280.4140	2	8140.2070	0.262	0.770	
phscs/d	4471027.2808	144	31048.8006			
dphsc	164389.9823	4	41097.4956	1.324	0.264	
phscs/d	4471027.2808	144	31048.8006			

ior	59438908.5619	3	19812969.5206	238.139	0.000	***
is/d	17971042.9138	216	83199.2727			
di	451683.8316	6	75280.6386	0.905	0.492	
is/d	17971042.9138	216	83199.2727			
pi	114965.3996	3	38321.7999	1.134	0.336	
pis/d	7297059.3829	216	33782.6823			
dpi	69237.6290	6	11539.6048	0.342	0.914	
pis/d	7297059.3829	216	33782.6823			
hi	707689.9425	3	235896.6475	4.781	0.003	**
his/d	10656589.8837	216	49336.0643			
dhi	313473.4810	6	52245.5802	1.059	0.388	
his/d	10656589.8837	216	49336.0643			
phi	52248.8618	3	17416.2873	0.400	0.753	
phis/d	9402061.1354	216	43528.0608			
dphi	452013.1434	6	75335.5239	1.731	0.115	
phis/d	9402061.1354	216	43528.0608			
si	826225.9620	6	137704.3270	2.606	0.017	*
sis/d	22830857.2025	432	52849.2065			
dsi	920279.2313	12	76689.9359	1.451	0.140	
sis/d	22830857.2025	432	52849.2065			
psi	175321.8310	6	29220.3052	0.823	0.552	
psis/d	15332720.1108	432	35492.4077			
dpsi	624305.4123	12	52025.4510	1.466	0.134	
psis/d	15332720.1108	432	35492.4077			
hsi	606873.1069	6	101145.5178	2.776	0.012	*
hsis/d	15739736.1075	432	36434.5743			
dhsi	287009.1815	12	23917.4318	0.656	0.793	
hsis/d	15739736.1075	432	36434.5743			
phsi	107118.5734	6	17853.0956	0.592	0.736	
phsis/d	13018094.9633	432	30134.4791			
dphsi	279478.2133	12	23289.8511	0.773	0.679	
phsis/d	13018094.9633	432	30134.4791			
ci	1575491.2453	3	525163.7484	10.455	0.000	***
cis/d	10849666.4846	216	50229.9374			
dci	374711.5566	6	62451.9261	1.243	0.285	
cis/d	10849666.4846	216	50229.9374			
pci	95590.1646	3	31863.3882	0.998	0.394	
pcis/d	6892884.1121	216	31911.5005			
dpci	178148.6973	6	29691.4495	0.930	0.474	
pcis/d	6892884.1121	216	31911.5005			
hci	831235.7203	3	277078.5734	6.695	0.000	***
hcis/d	8939025.8204	216	41384.3788			
dhci	284787.1416	6	47464.5236	1.147	0.336	
hcis/d	8939025.8204	216	41384.3788			
phci	29742.7357	3	9914.2452	0.260	0.854	
phcis/d	8223872.3637	216	38073.4832			

dphci	211312.7912	6	35218.7985	0.925	0.478
phcis/d	8223872.3637	216	38073.4832		
sci	357717.6908	6	59619.6151	1.611	0.142
scis/d	15988384.8392	432	37010.1501		
dsci	350568.5430	12	29214.0452	0.789	0.662
scis/d	15988384.8392	432	37010.1501		
psci	178306.7498	6	29717.7916	0.781	0.585
pscis/d	16435500.2392	432	38045.1394		
dpsci	782235.2715	12	65186.2726	1.713	0.061
pscis/d	16435500.2392	432	38045.1394		
hsci	240934.0762	6	40155.6794	1.104	0.359
hscis/d	15712945.9233	432	36372.5600		
dhsci	432542.3651	12	36045.1971	0.991	0.456
hscis/d	15712945.9233	432	36372.5600		
phsci	208671.1466	6	34778.5244	0.721	0.633
phscis/d	20828173.3525	432	48213.3642		
dphsci	889637.2822	12	74136.4402	1.538	0.108
phscis/d	20828173.3525	432	48213.3642		