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ABSTRACT

This paper investigates the processes by which visual mental images--the precept-like short-term memory representations--are created from information stored in long-term memory. It also presents a new method for studying image generation. Three experiments were conducted using college students as subjects. In the first experiment, a Podgorny and Shephard paradigm was adapted to study image generation. In the second experiment, regression analyses were performed on response times in a scanning instruction and no-scanning instruction condition. Experiment three was designed to investigate whether scanning plays a functional role in image generation. Results indicated that images of upper case letters are formed segment by segment, in roughly the order in which most people draw the letters. Results were shown not to be an artifact of how people scan images once they are formed, and could not have been due to experimenter-expectancy effects. Results also indicated that subjective estimates of mental image generation time are quite close to those obtained using objective measures. (Author/LMO)

SEQUENTIAL PROCESSES IN IMAGE GENERATION: AN OBJECTIVE MEASURE

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Are visual mental images of objects created a part at a time? This paper reports an new objective technique that was developed to answer questions such as this one. The results of using this technique indicated that images of upper case letters are formed segment by segment, in roughly the order in which most people draw the letters. These results were shown not to be an artifact of how people scan over images once they are formed, and could not have been due to experimenter-expectancy effects. In addition, the results indicated that subjective estimates of mental image generation time are quite close to those obtained using objective measures.

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Sequential Processes in Image Generation: An Objective Measure

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Abstract

Are visual mental images of objects created a part at a time? The results reported in this paper indicate that images of upper case letters are formed segment by segment, in roughly the order in which most people draw the letters. These results were shown not to be an artifact of how people scan over images once they are formed, and could not have been due to experimenter-expectancy effects. In addition, the results indicated that subjective estimates of mental image generation time are quite close to those obtained using objective measures.

Sequential Processes in Image Generation: An Objective Measure

One of the most fundamental observations about mental images is that we somehow create them on the basis of stored information. Images are transient, percept-like representations that exist in short-term memory. When we do not experience imagery, the information necessary to create images presumably resides only in long-term memory; images proper must arise as a consequence of this information being processed. In this paper we investigate the processes by which visual mental images—the percept-like short-term memory representations—are created from information stored in long-term memory.

It often is assumed that images are generated on the basis of stored information (see chapter 6 of Kosslyn, 1980, for a review). This generation process purportedly entails the activation of individually-stored units of information, which are amalgamated into a single composite representation. Such image generation is thought to occur not only when subjects image objects arranged into a scene (e.g., a dog chasing a car that has a monkey riding on the roof), but when parts of a single object are imaged (e.g., on a bicycle, the wheels, handles, and so on); we presume that the units being activated were initially parsed and encoded during perception. A basic question one can ask about such a generation process is whether parts are imaged simultaneously. or whether parts are added sequentially. In this paper we demonstrate that segments of letters are imaged one at a time in sequence.

In addition to investigating the serial nature of the image generation process, in this paper we present a new, "objective" methodology for studying image generation. Image generation has to date been studied using three kinds of methodologies, all of which have their weaknesses: First, and most directly, subjects have been asked simply to press a button when an image of a given named object or scene has been formed (e.g., Beech and Allport, 1978; Kosslyn, Reiser, Farah and Fliegel, 1983; Moore, 1915; Paivio, 1975). It has been found repeatedly that subjects take more time to respond when asked to image more "complex" patterns (e.g., scenes including more objects; pictures of animals that include more details). These data are taken as evidence that subjects actively generate the image from individually stored parts of some sort (see Kosslyn et al. 1983). Unfortunately, on the face of things this methodology would seem to have some severe drawbacks, hinging on the fact that it is highly subjective: it not only depends on subjects' knowing when an image is "completely formed," but on their cooperation and good will. In addition, given the subjective nature of the judgment, the technique seems especially susceptible to possible experimenter demand effects and task demands (see Intons-Peterson, 1983; Pylyshyn, 1981). Furthermore, it may not be a good measure of image generation per se; after the image is formed, the subject may scan around and "inspect" it prior to pressing the button. If so, then the response time may reflect the time to inspect an image in addition to the time to generate it, and we cannot assume to know the relative contributions of the two kinds of processes to the overall times.

The second methodology has the advantage of incorporating an objective task. Weber and his colleagues (e.g., Weber and Bach, 1969; Weber and Castleman, 1970; Weber, Kelley and Little, 1972) have asked subjects to judge from memory the relative height of lower case letters of the alphabet (e.g., "medium, high, medium, high" for the first four letters of the alphabet). This task does not require subjects to decide when an image has been formed, but it does require a judgment about the imaged letter after it is available. Thus, the response times reflect the operation of both the image generation and inspection processes, in addition to the decision processes, and we cannot identify the relative contributions of the different processes. In addition, given that a series of images usually are created in sequence, some of the time to make the judgment may reflect the time for the previous image to fade. Furthermore, the task is very stimulus-specific, and in particular seems ill-suited for investigations of the processes used to form images of individual patterns (such as single letters).

The third methodology involves asking subjects to study a pattern, and then to decide whether a second pattern was a component of the first one (e.g., Reed, 1974; Reed and Johnsen, 1975). For example, subjects might study the Star of David, and then decide whether a parallelogram was contained within it. This methodology also is objective. However, it lacks face validity: There simply is no evidence that imagery is involved in this task. In addition, the generation component is again conflated with image inspection processes. Furthermore, the methodology is not easily used to answer questions of the form being asked here, such as whether individual stored units are activated sequentially.

The present experiments rely on a new methodology, which seems to have the strengths of the earlier objective techniques and the flexibility and face validity of the subjective technique.

Experiment 1

The methodology used in this experiment is derived from a task developed by Podgorny and Shepard (1978). In one condition, they showed subjects a 5-by-5 matrix, and blacked out specific cells so that a letter was displayed. Shortly thereafter, one or more dots appeared in the grid, and subjects were asked to decide if all of the dots fell on the figure. In a second condition, the subjects saw a blank matrix, and now imaged the letter as if the appropriate cells had been blacked out. After forming the image, the subjects then decided whether dots fell in cells that were imagined to be blacked out. Podgorny and Shepard found remarkably similar patterns of reaction times in the two conditions. Times in both cases depended on whether dots fell on intersections or limbs, the size of the figure, and the number of dots. In addition, Podgorny and Shepard reported that there was no evidence of top to bottom or left to right scanning or the like; in both cases, the cells apparently could be monitored in parallel.

We have adapted the Podgorny and Shepard paradigm to study image generation in the following way: Subjects are shown a blank grid along with a lower case letter. They are told to image the upper case version of the letter in the matrix, and to decide whether two x marks fall in cells occupied by the image. The x marks appear only 500 msec after the lower-case cue appears, which--if previous estimates of image generation time are anywhere near correct--is not enough time to read the cue and finish generating an image. Thus, some additional time will be required to generate the image prior to evaluating the probes, with more time being required when more of an image must be formed. Thus, if more complex forms require more time to image, differences in image complexity ought to be reflected by differences in evaluation time in this task.

The task just described involves not only forming an image, but "inspecting" it and making a decision about the relationship between the probe marks and imaged pattern. Given Podgorny and Shepard's results, it seems that the same factors affect inspecting a physically present display and an image. Thus, we included a perceptual condition exactly analogous to the imagery one, except that the appropriate cells were actually filled. The times from this task were then subtracted from the imagery ones, which should eliminate the contribution of the inspection and evaluation processes from the response times in the image generation task.

The most important feature of this experiment is that, in addition to varying the complexity of the letters, we systematically varied the locations of the probe marks on key trials. On some trials, both probe marks were located on segments that should be generated near the beginning of the sequence, if we suppose that a letter's segments are imaged in the sequence they are usually drawn or that the single longest line is generated first and each connecting link is thereafter generated in order. On other trials, one of the probe marks was located on a "far" segment, which should be imaged at the end of the sequence, and thus this probe should take more time to evaluate because one will have to wait longer for the segment to be generated. If the generation sequence is really at the root of such an effect, of course, then we expect no such result when the subjects evaluate marks on physically present letters.

In order to compare our new measure of image generation time with the traditional subjective method, we also included a third task. Here the subjects saw a lower-case cue, and formed an image of the upper case version of the letter in the grid. When the image was complete, the subject simply pressed a button. The time to press the button, reporting that the image was formed, was measured. We compared the differences in image generation times (among the different letters) obtained from the button press technique with the differences obtained from the new objective measure. If both measures in fact gauge image generation time, then we should find similar effects of the complexity of the imaged letters in both cases.

Finally, in addition to examining the time to push the button in this last task, we examined the time to evaluate the probes when they were presented after the image was fully generated. That is, after the subject pressed a button to indicate that an image had been formed in the subjective image generation task, two *x* marks appeared and the subject decided whether they fell in cells occupied by the imaged figure. This task is very similar to one studied by Podgorny & Shepard (1978), and we wished to contrast their results on image *inspection*, which suggested a parallel search, with the present predictions on image *generation*, which posit a serial process. If an image can be searched in parallel once formed, then we should not find effects of near vs. far probes on these response times.

Method

Subjects

Twelve Johns Hopkins University undergraduate students volunteered to participate as paid subjects.

Materials

A 4 x 5 grid was displayed on a video display monitor (subtending approximately 6 x 8 degrees of visual angle), and a program was written to form the upper case versions of the letters L, C, J, G, H, F, P and U by selectively filling in the appropriate cells. The lower case version of the letter was presented directly beneath the grid, using the standard APPLE computer font. We were interested primarily in responses to the letters L and C (simple letters) and J and G (complex letters); the additional letters were included in part as fillers, so that no particular locations in the grid were especially likely to be the location of a probe mark.

The computer was programmed to deliver three types of trials: In one type, a letter was actually displayed by filling in the appropriate cells of the grid, and the lower case version was presented beneath the grid; 500 msec after the stimulus was presented, an x mark appeared in two of the cells of the grid. Each x appeared in the center of a cell and remained on until the subject responded. On half the trials both marks fell on the block letter (these were "true" trials), and on the other half only one mark fell on the letter (these were "false" trials). When a probe mark was off the letter it fell in a cell located adjacent to the letter. Each letter was presented 20 times, 10 with both probe marks on it and 10 with only one mark on it. The presentation sequence was random except that each of the 16 stimulus types (true and false trials for each of the 8 letters) appeared an equal number of times in each block of 80 trials; the same sequence of trials was used in all three conditions. A new trial was presented five sec after the subject had made a decision.

For the letters "G" and "J" the "true" trials were divided into two types: "Near" trials had one x mark on the spine (the single longest line, the vertical line on the left of the "G" and on the right of the "J") and another on a segment adjacent to the spine (e.g., the bottom of the G). "Far" trials had one x mark on the spine and one on a segment separated from the spine by the maximum possible number of intervening segments (i.e., the short inward-turning horizontal segment at the right of the G or the vertical tip of the hook on the left of the J). The probe marks in the "near" condition were separated by a mean of 5.7 cm and 5.5 cm on the screen for the J and G, respectively; the probe marks in the "far" condition were separated on the screen by a mean of 4.5 cm for both letters. Thus, although we expected "far" segments to be generated further apart in the generation sequence, the marks were actually closer together on the screen than the "near" marks. The different stimuli are illustrated in Figure 1.

INSERT FIGURE 1 ABOUT HERE

Another type of trial was exactly like type just described except that none of the cells of the matrix were filled in. The lower case letter was presented centered beneath the empty matrix, and the probe marks appeared 500 msec after the grid and lower case letter were presented.

The remaining type of trial also began by presenting an empty grid with a lower case letter centered beneath it. However, in this case the probe marks were presented 500 msec after the subject pressed a button (indicating that he or she had finished forming the image). The time between the presentation of the grid (and cue) and this button press was measured. In all three conditions the time for a subject to respond to the probe marks was measured, with the clock starting when the probes were presented and stopping when either of two response keys were pressed. The computer recorded all times as well as the responses themselves.

All types of trials were preceded by 8 practice trials in which each letter appeared once; half of these trials had "true" probes and half had "false" probes.

Procedure

The session began with a series of study trials to familiarize the subjects with the block letters as they appeared in the grid. They were first shown an empty grid with the lower case version of the letter beneath it. The appropriate cells of the grid were then filled in to form the corresponding upper case letter. The subjects were asked to study each letter until they could close their eyes and form an image of it as it appeared in the grid, and were given as much time and as many exposures to the letters as was needed for them to report being able to form good images of the stimuli.

All subjects participated in three tasks. Half of the subjects received the Button Push Condition, followed by the Brief Delay Condition, and half received the Brief Delay Condition first followed by the Button Push Condition. The Perceptual Condition was always administered last because we worried that the subjects might begin to learn where the probe marks appeared, which would obviate the need for imagery in the other conditions.

In the Perceptual Condition the subjects were told simply to indicate whether or not both probe marks fell on the visible block letter. If so, they were to press the key labeled "yes;" if not, they were to press the key labeled "no." The "z" and "/" keys of the APPLE keyboard were used for responses.

Within each counterbalancing group, half the subjects responded "true" by pressing the key beneath their dominant hand and half responded "true" by pressing the key beneath their nondominant hand; the remaining key was used to respond "false." The response keys were kept constant for all of the tasks.

In the Brief Delay Condition the subjects were told to decide whether both probe marks would have fallen on the upper case version of the lower case cue letter located beneath the grid. That is, they were asked, "If the corresponding block letter were displayed in the grid, would both marks fall in cells that were filled?" Again, responses were made by pressing the appropriate key.

In the Button Push Condition there were two responses: First, upon seeing the empty grid and lower case cue, subjects were to "project" an image of the corresponding upper case letter (as previously studied) into the grid. As soon as the image was complete, the subject was to press the button also used to indicate "true" decisions. Five hundred msec after making the response, the probe marks appeared and the subject decided whether both would have fallen on the letter had it actually been present in the grid. In all conditions subjects were urged to respond as quickly as possible while keeping errors to a minimum.

Results

Results from the "true" trials from all conditions were analyzed. Only the true trials were considered because only in these cases did we know how much of the letter had to be imaged to make the judgment. We began by considering the results of analyses of variance, focusing primarily on the effects of letter complexity. We next turned to analyses of effects of probe position, now considering analyses of variance and correlations; the mean response times for each stimulus were correlated with the number of links that should have been generated in an image of the letter before being able to evaluate the farthest probe. In addition, we also examined the partial correlation, after the first correlation was removed, between times and the distance a subject would have to scan if inspecting the letter from its beginning to the farthest probe (distance was measured from the place where one starts to print the letter, in mm on the screen, for each stimulus). This last correlation was performed to discover whether subjects were scanning images after they were generated, as will be discussed shortly.

Image generation

The data of primary interest were from the visually simple letters, L and C, and the visually complex letters, J and G. The first question we wanted to answer was whether the subjective button-press measure of image generation and our new measure tap the same underlying processing. The results from the simple button pressing task replicated previous findings, with more time being taken for the complex letters than the simple ones (1514 vs. 1232 msec), $F(1, 11) = 18.43$, $p < .002$.

Similarly, in the Brief Delay Condition the complex letters required more time to evaluate than the simple ones (1234 vs. 872 msec), $F(1, 11) = 38.32$, $p < .0002$.

The data from the Perceptual Condition were collected to be used as a baseline. The analysis of these data again revealed that more time was required to examine the complex letters than to examine the simple ones (498 vs. 478 msec), $F(1, 11) = 9.90$, $p < .01$.

We next derived our objective measure of the difference in image generation time for the simple and complex letters. For each subject, we simply subtracted the time in the Perceptual Condition for each of the probes for each letter from the corresponding time in the Brief Delay Condition. The overall difference between the complex and simple letters in this measure was 344 msec, compared to a difference of 282 msec in the Button Push task. In a single analysis including the derived measure and Button Push times, we found that complexity had the same effects on both measures, $F < 1$ for the interaction of measure and complexity. The Button Push times were of course longer (because they include the time to encode the cue and to make a response), $F(1, 11) = 22.17$, $p < .001$, and more time was generally required for the more complex letters, $F(1, 11) = 44.63$, $p < .0001$. The finding that complexity had equivalent effects in the two measures is particularly important because the derived measure is uncontaminated by possible effects of complexity on the inspection, decision, or response processes. Finally, we correlated the Button Push times for all 8 letters with those from the "far" probes in the Derived Measure, which should have required completing most of the image; this correlation was $\underline{r} = .85$. In short, we found evidence that the subjective button-press task is a reasonable index of differences in image generation time.

The fact that images of more complex patterns require more time to form supports the notion that segments are generated individually, but does not tell us whether segments are imaged sequentially. Our next set of analyses addressed the question of whether images of some parts of the letters are generated before others. We now examined the effects of "near" versus "far" probes for the two complex letters in the Brief Delay Condition. First, response times for near probes were in fact faster than those for far probes (1121 vs. 1351 msec, respectively), $F(1, 11) = 14.39$, $p < .005$. Second, there was no effect of letter (J vs. G), $F < 1$. And third, the effects of near vs. far probes were the same for the two letters, even though the far probes were to the left on the J and to the right on the G, $F = 1.06$ for the appropriate interaction; thus the effects of trial type are not an artifact of left-right scanning. Consistent with these results is the finding that the correlation between the mean response times and the number of segments to the second probe mark was $\underline{r} = .80$; when this correlation was removed, the partial correlation between the response times and distance to the second mark was $\underline{r} = .24$.

We next examined the effects of near vs. far probes in the Perceptual Condition. The results of this analysis are easy to summarize: There was absolutely no hint of an effect of near vs. far probe position or of interactions with this factor, $p > .20$ in all cases (the means were 497 vs. 499 msec for near vs. far, respectively). In another analysis we compared the times from the Perceptual Condition with those from the Brief Delay Condition, and found that near vs. far probes do indeed affect the two measures differently, $F(1, 11) = 11.57$, $p < .01$, for the interaction between probe type and condition. The correlation between the response times for each of the stimuli and the number of segments in a letter from the beginning to the second x mark was $\underline{r} = .24$; this correlation contrasts with the .80 correlation found in the Brief Delay condition, which is consistent with the claim that effects of segments reflect image generation per se. When this correlation was removed, the partial correlation between the times and the total distance between the beginning and the second x mark was $r = .53$, which may suggest that some scanning occurs when subjects inspect the actual stimuli.

Given the results of the analysis of the perceptual baseline, it is not surprising that we found effects of near vs. far probes on our derived image generation measure, $F(1, 11) = 11.55$, $p < .01$. And, as before, the effects were the same for both letters, $F(1, 11) = 2.14$, $p > .15$. The correlation between the mean derived image generation times for each stimulus and the number of segments to the second x mark was $r = .80$; the partial correlation with distance was $r = .13$.

Between-subject perceptual control group. We next considered the results from a separate Perceptual Condition group, which was tested as a control for possible practice or fatigue effects in the within-subjects Perceptual Condition. This group of 12 Harvard University undergraduates (volunteers who were paid for their participation) was tested by a different experimenter who was ignorant of the purposes and predictions of the experiment. The method and procedure used here were identical to those used for the previous group.

The results of testing this group were similar to those found for the original within-subjects Perceptual Condition. However, now there was no difference between the different types of probes: The means were 475 and 474 msec for the simple and complex letters on true trials, $F < 1$, and no other effect or interaction was significant, $p > .25$ in all cases. An analysis of the effects of near vs. far probes again revealed absolutely no effect of probe location, with means of 478 and 471 msec for the two types of trials, respectively, $F < 1$. The correlation between the mean response times and the number of segments to the second probe mark was $r = .20$; the partial correlation with distance was $r = .13$.

The data from this group were considered in a single analysis with the data from the initial within-subject Perceptual Condition. Not only was there no significant effect of group, $F < 1$, but there were no interactions with group, $p > .13$ in all cases. Similarly, there were no significant interactions or main effects when we analyzed only the data from the near vs. far trials in the two groups, $p > .15$ in all cases.

Apparently, the results from the within-subject Perceptual Condition were not contaminated by the preceding imagery tasks. Indeed, the magnitude of the complexity effect in the two Perceptual Condition groups differed by only 19 msec., and the disparity in the difference between near and far probe types in the two conditions was only 5 msec.

We could not subtract a corresponding baseline score from each Brief Delay score to derive our objective measure here, because the same subject did not participate in both conditions. However, the same message comes through when we analyze the data from the Brief Delay Condition together with the data from the between-subjects perceptual baseline. Most important, we obtained a significant interaction between complexity and condition, $F(1, 22) = 36.31$, $p < .0001$, documenting the selective effect of complexity in the imagery condition. In addition, we found that the imagery condition required more time in general $F(1, 22) = 30.35$, $p < .0001$, and that complex letters required more time in general, $F(1, 22) = 36.03$, $p < .0001$. No other effects or interactions were significant, $p > .35$ in all cases.

A combined analysis was also conducted to compare only the near vs. far trials in the between-subject Perceptual Condition and the Brief Delay Condition. Most important, we again found a significant interaction between Condition and probe location, F(1, 22) = 13.98, $p < .002$. The difference between the trials with near probes and those with far probes was only 7 msec in the Perceptual Condition, compared to 230 msec in the imagery condition. In addition, the imagery condition required generally more time, F(1, 22) = 34.93, $p < .0001$, and there was in general an effect of probe location, F(1, 22) = 12.48, $p < .002$. No other effects or interactions were significant, $p > .25$ in all cases.

Image inspection

We now turn to an analysis of the judgment times following the Button Push task (i.e., when an image had been formed prior to presentation of the probes) for the subjects in the within-subjects group. This task should involve image inspection but not image generation. We again found that more time was required to evaluate the more complex letters (670 vs. 763 msec for simple and complex letters, respectively), F(1, 11) = 10.76, $p < .01$. These results, along with the previous ones, are illustrated in Figure 2. Perhaps most interesting, a separate analysis of "near" versus "far" probes revealed that, unlike the data in the Brief Delay Condition, far probes did not require more time than near ones (804 vs. 722 msec), F(1, 11) = 1.70, $p > .2$; this was true for both stimulus letters, F < 1 for the appropriate interaction. The correlation between the mean response times and the number of segments to the second probe mark was $\underline{r} = .48$; the partial correlation with distance was $\underline{r} = .42$. The means of the near and far probe locations in the various conditions are presented in Figure 3.

INSERT FIGURES 2, 3, AND TABLE 1 HERE

We next compared our derived measure of image generation time with the time to inspect the image when it was generated before the probes were presented. As is evident in Figure 2, there were diminished effects of complexity in the inspection task, $F(1, 11) = 23.96$, $p < .001$, for the interaction of Condition and Complexity. In addition, there was a 338 msec overall advantage in inspecting a previously formed image relative to the Brief Delay Condition, in which subjects had only 500 msec to read the lower case cue and begin to prepare before the probes appeared, $F(1, 11) = 9.48$, $p < .02$.

We also compared the time to inspect the image after it was generated with the time to inspect the physically-present figures in the within-subject Perceptual Condition, which are the two conditions originally examined by Podgorny and Shepard (1978). There was only one interaction with Condition, due to the complexity of the stimulus: There were diminished effects of complexity in the Perceptual Condition, $F(1, 11) = 6.47$, $p < .03$. In addition, the subjects responded more quickly in the Perceptual Condition, $F(1, 11) = 15.74$, $p < .003$.

Finally, we compared the effects of the two probe locations in image inspection times versus the other two measures. The effects of probe location fell between those observed in the other measures, resulting in only a marginal interaction with Condition in the analysis comparing inspection times with the derived image generation data, $F(1, 11) = 3.82$, $p < .08$, and no interaction in the analysis comparing inspection times with the perceptual baseline, $F(1, 11) = 1.52$, $p > .20$.

The error rates for the various conditions are presented in Table 1.

Discussion

There was good convergence in the results from the simple button press task traditionally used to measure image formation time and the new derived measure, with the effects of letter complexity being similar in the two measures. It would appear that subjects are reasonably good judges of when an image has been generated.

The results from the "near" versus "far" trials provide the first support for the claim that segments of a form are imaged sequentially. The effect did not occur in the analogous perceptual task or image inspection task, and was present even when we subtracted the perceptual data from the image generation task data, thereby factoring out the encoding, decision, and response components of the task. In particular, the fact that these effects were not present in the image inspection data provides evidence that these effects reflect image generation per se. The correlational analyses dovetailed nicely with these results, with the number of segments necessary to image before being able to evaluate the probe mark on the "farthest" segment correlating highly with response times in the derived measure of image generation time. It is of interest that these correlations were low in the perceptual task and in the image inspection task—neither of which required image generation.

One might attempt to argue that the present results do not indicate that images of segments are generated one at a time. Instead, perhaps the image of a letter is formed all of a piece, but then is scanned over while being inspected. If so, then the more scanning that occurs, the more time will be required. We examined the partial correlations with actual distance to the second probe mark in order to consider this hypothesis. That is, it has been found repeatedly that response times increase systematically with the distance traversed when imaged patterns are scanned (see chapters 3 and 7, Kosslyn, 1980). There were no effects of distance per se when effects of the number of segments were removed, counter to what is predicted by the scanning theory. A variant of this theory attributes the effects of complexity and probe position not to scanning over the letter, but to systematic left-right scanning over the screen; such scanning again would be used after the image was formed. However, the effects of probe position in the image generation task were obtained when the "far" segment was to the left or to the right of the "near" one, and hence these effects cannot be due to a such a scanning strategy over the screen. In addition, the probe marks in the "near" pairs were actually physically farther apart on the display than were the x marks in the "far" pairs, but nevertheless near probes required less time than far ones.

Experiment 2

The results of Experiment 1 suggest that the effects of complexity and of probe location are not simply artifacts of scanning after the image is formed. However, this inference is based on a null finding: the lack of a significant correlation between distance and response times, after the effects of number of segments have been partialed out. It is possible that this measure is simply too insensitive to detect distance effects. To examine this possibility, we now repeat the Brief Delay Condition used in Experiment 1 and compare these results to those from an additional condition, in which subjects explicitly are instructed to scan over their images of the letters in the course of searching for the two probe marks. When subjects are instructed to scan their images, response times should increase with increasing distance traversed (see Finke & Pinker, 1982, 1983; Jolicoeur & Kosslyn, in press; Kosslyn, Ball & Reiser, 1978); if they do not, the paradigm is insensitive to scanning effects. If we do obtain effects of distance when subjects are instructed to scan, but not otherwise, this is evidence that subjects do not spontaneously scan over their images before responding.

Thus, in the present experiment we perform regression analyses on the response times in a scanning instruction and no-scanning instruction condition, comparing how well these times are predicted by various measures of the number of segments presumably imaged and the distance presumably scanned before one can "see" that both probe marks fall on the letter.

Even if distance does not generally correlate with response times when scanning instructions are not given, this finding would not rule out the possibility that some scanning is used in image generation. In particular, some subjects in Experiment 1 claimed that the locations of "near" probes were on segments that required careful attention when generating the image, being connections between two major segments and being rather tight curves. The present experiment was also designed to investigate this possibility. The precise positions of the probe marks along a single segment are varied; if the segment is scanned when being imaged, these variations would affect response times.

Finally, this experiment takes an additional precaution not used in the within-subjects conditions of the first experiment: the experimenters were totally ignorant of the hypotheses and predictions of this experiment and of the results of the first experiment. This precaution eliminates any possible effects of experimenter expectancy (see Intons-Peterson, 1983).

Method

Subjects

Twenty-four subjects were tested, all of whom were Harvard University undergraduates. Half of the subjects participated in one condition, and half participated in the other. The subjects volunteered to participate for pay; no subject participated in Experiment 1.

Materials

The stimuli used in the Brief Delay Condition of Experiment 1 were also used here. However, the stimulus set was modified by including two versions of the "near" trials for the letters J and G: "Near-close" trials had the second x (not on the spine) closer to the spine, and "near-far" trials had the second x further from the spine on the same segment as the corresponding "near-close" trial. The two types of trials are illustrated in Figure 4. Six trials of each type for "G" and for "J" were included. In addition, only four of the J and G "far" trials used before were used here. The stimuli were randomized with the same constraints used in Experiment 1, and the same sequence was used in both conditions.

INSERT FIGURE 4 HERE

We also drew on paper a set of 4 x 5 grids, and formed the letters within them by blacking out the appropriate squares. Arrows were drawn showing the direction in which the strokes are usually drawn (as determined by a consensus of the experimenters and people around the lab). These materials were used to familiarize subjects with the idea of scanning along the letter in search of the probe marks.

Procedure

This experiment used a purely between-subjects design, with each subject being tested in only one condition, which resulted in less load on individual subjects and eliminated any possible order effects between conditions. This design seemed reasonable in light of the results of Experiment 1. In addition, a different experimenter tested the subjects in each condition of the experiment; both experimenters were ignorant of the purposes and predictions of the experiment and of the other condition being tested. The instructions and procedure for the No Scanning Instruction Condition were identical to those used in the Brief Delay Condition of Experiment 1.

The Scanning Condition was like the No Scanning Instruction Condition except that subjects were told to image the letter in the grid, and then to mentally scan along it, tracing out the pathway shown in the sample drawing of the letter. Subjects first were asked to study the sample materials and to draw each letter, indicating the direction of scan by the way the letter was drawn. The subjects were asked to memorize the scan paths, and were tested until they could draw each of the scan paths correctly from memory. Following this, they were told that we did not want them to respond in the probe-evaluation task until they had scanned along their image and passed over both x marks, or had scanned over the entire letter and not "seen" both marks.

We did not test an additional group in the Perceptual Condition for two reasons: First, the data from the between-subjects Perceptual Condition of Experiment 1 indicated no effects of complexity or probe type; these results suggest that effects of complexity and probe type are not due to encoding, evaluation, or response processes. Second, the same mean baseline times (or very similar times) would be subtracted from the Scanning and No Scanning data; subtracting the same numbers from each would not alter the relative effects of number of segments and distance in the two conditions. In this experiment we are not concerned with obtaining an accurate estimate of image generation time per se, but only with the relative magnitude of effects in the two conditions. Thus, given the question being asked here, we have no need to obtain data from another perceptual baseline group.

As before, 8 practice trials were given at the outset of each condition and subjects were urged to respond as quickly as possible, keeping errors to a minimum while fully following the instructions.

Results

We again focused on the results from the "true" trials, where we had a basis for estimating how much of the image should have been formed. We were most interested in the results of a set of multiple regression analyses. These analyses had two goals: further examination of the effects of distance in the two conditions, and discovery of the best principle to describe the order in which segments are generated into the image. We began by computing the mean verification time (pooling over subjects) for each "true" trial for each probe of each letter; separate means were computed for the two conditions. We then regressed these means onto a number of independent variables, performing separate analyses for the two conditions. We were interested in which variable was entered first in a stepwise procedure, and in which variables accounted for significant amounts of the variance.

Four different measures of segment number were included to allow us to evaluate different theories of the order of part generation. Specifically, we considered: (a) the number of segments from the beginning of the letter (as it is printed in the grid) to the farthest probe mark, which will be important if subjects generate images from the beginning of a letter until the second x has been "covered" by a segment; (b) the number of segments between the two probe marks, which will be important if the subjects generate enough segments of an image to evaluate the first probe mark when it is presented, without additional image generation, and thereafter only generate new segments until the second x is "covered"; (c) the number of segments to the farthest probe mark from the longest single stroke (the spine), which will be important if the single longest stroke serves as the "skeletal image" to which all other parts are attached; and, (d) the total number of squares occupied by a particular letter, which will be important if the separate filled cells, and not letter strokes, are imaged individually. This last variable is important in part because it allows us to examine effects of distance per se, as opposed to the number of squares that must be generated.

In addition, four measures of distance were included to help us examine possible effects of scanning during image generation and/or inspection. Specifically, we considered: (a) the distance (in mm) along the scan path from the beginning of the letter to the farthest probe mark, which will be important if the letter is imaged all of a piece and then scanned along until the second mark is found; (b) the distance between the probe marks, which will be important if the letter is imaged all of a piece and then scanned from the location of the first mark to the second or if special care is given to generation of these segments, resulting in some scanning; (c) the distance (in mm) from the beginning of the letter to the second probe, not including the distance from the first probe to the end of the segment it is on, which will be important if subjects scan to the first probe and then jump to the next segment to continue scanning; and, (d) the total distance from the beginning to the end of the letter, which will be important if subjects exhaustively scan the letter (not stopping when they reach the second probe).

In our regression analysis of the No Scanning Instruction Condition data, we found that the number of segments between the two probes was entered first in our step-wise procedure, with $\underline{r} = .70$. When this correlation was partialed out, none of the other measures was significantly related to response times, $p > .10$ in all cases. The multiple R including all variables in the equation was .78. Of particular interest is the finding that the distance (in mm) from the beginning of a letter to the second probe was correlated only $\underline{r} = .39$ with response time when number of segments between probes was partialed out.

It is not surprising that the number of segments between probes was the variable that was entered first into the equation for the No Scanning Condition data. The probes were presented 500 msec after the subjects saw the lower case cue, which should have allowed them to get a start on image generation before the probes were presented. If so, then the segment covering the first probe mark may often have been imaged before the mark appeared, and the critical variable was how many segments remained to be generated between the two marks.

In our analysis of the Scanning Condition, the distance (in mm) from the beginning to the second probe was entered first, $r = .62$, $p < .01$. The failure to find that scanning resulted in more time in general (see below) suggests that subjects scanned segments as they were generating them, and not after the entire image was formed. Presumably, this joint operation was slow enough that there was not enough time to finish generating and scanning the initial segment before the probes appeared, and thus distance from the beginning--and not between the probes--was most important. No other variable was significantly correlated with the response times when distance was partialed out, $p > .10$ in all cases. The multiple R including all variables was .77.

Effects on a single segment

We next performed analyses of variance in order to examine in more detail the two sorts of "near" trials for the letters G and J. In both types of trials, one probe mark fell on the spine, and the other fell on another segment (see Figure 4); the position of the probe mark on the non-spine segment was varied: on one trial the x was to the right on the segment, whereas on the other it was to the left. The effects of position were significant in the No Scanning Instruction Condition, $F(1, 11), = 17.43$, $p < .002$ (for J, the near-close and near-far trials were 1193 and 1358 msec; for G, 1144 and 1350 msec). This effect was consistent for both letters, $F < 1$ for the interaction of letter and distance. The effect of position was also significant in the Scanning Condition, $F(1, 11) = 28.10$, $p < .0005$ (for J, 1332 and 1532 msec; for G, 1481 and 1673 msec). This effect reflects the fact that different distances had to be scanned for the two probe types. In addition, more time was generally required for the letter G, $F(1, 11) = 6.98$, $p < .03$. It is not surprising that we found faster times overall for J, given that there was a smaller difference in distance between the two probe locations (see Figure 4).

A combined analysis was also carried out on the data from the two near trials in the two conditions. In this analysis there was a significant difference between near-close and near-far trials, $F(1, 22) = 43.57$, $p < .0001$. There was no hint of an interaction between condition and distance, $F < 1$. However, there was a near-significant trend for a greater difference between G and J in the Scanning Condition (1577 vs 1432 msec) compared to the No Scanning Condition (1247 vs. 1275 msec), $F(1, 22) = 3.90$, $p = .06$; this trend makes sense because there was a greater distance to scan between the probes for G (see Figure 3). No other effects or interactions approached significance, $p > .15$ in all cases.

We also examined response times to probes in each of the three probe locations. As is evident in Figure 5, these results replicated those from the first experiment, with increasing time being required for probes located increasingly further along the letter. In an analysis including data from both conditions, the effect of probe location was highly significant $F(2, 44) = 44.71$, $p < .0001$. No other effect or interaction was significant in this analysis, $p > .25$ in all cases.

INSERT FIGURE 5 ABOUT HERE

We also analyzed the data to discover whether we had replicated our earlier findings. For data from the No Scanning Instruction Condition, we again found an effect of complexity, with means of 1109 and 1367 msec for the simple (L, C) and complex (J, G) letters, respectively, $F(1, 11) = 10.62$, $p < .01$. No other effects or interactions were significant in this analysis, $p > .09$ in all cases. These results, then, indicate that our earlier findings were not due to experimenter-expectancy effects, given that post-experiment debriefing revealed that the present experimenter remained ignorant of the design, purposes, and predictions of the experiment.

In analyzing the data from the Scanning Condition, we also found an effect of complexity, with means of 1193 msec for simple letters and 1606 msec for complex ones, $F(1, 11) = 51.15$, $p < .0001$. No other effects or interactions were significant here, $p > .35$ in all cases. Although the complexity effect was 155 msec larger in the Scanning Condition than in the No Scanning Condition, the appropriate interaction did not reach significance in an analysis including both sets of data, $F(1, 22) = 2.57$, $p = .12$. No other interaction with Condition was significant in this analysis, $p > .15$ in all cases. These results are illustrated in Figure 6.

INSERT FIGURE 6 ABOUT HERE

The errors for the different conditions are presented in Table 1. There was no evidence of a speed-accuracy tradeoff. Note that the error rates for the "far" trials in part reflect the fact that there were only four such trials per letter in this experiment.

Within-subject replication

Although there was a suggestion of an increased complexity effect in the Scanning Condition, this interaction was not significant. We were concerned that the between-subjects design introduced too much variability to detect this interaction, given the finding that there are great individual differences in image generation times (Kosslyn, Brunn, Cave & Wallach, 1984). In order to obtain more stable comparisons of the effects of the two types of instructions, the present experiment was replicated using a within-subjects design. Eleven Johns Hopkins University undergraduates participated as paid subjects. These subjects were tested by a new experimenter, who was ignorant of the purposes and predictions of the experiment. All subjects received the Scanning Condition after the No Scanning Condition in an effort to avoid their learning a scanning strategy prior to the No Scanning Condition. Exactly the same materials and procedure were used in these conditions as were used in the corresponding between-subjects conditions.

These data were again analyzed as were those in the between-subjects conditions, considering only the results from the "true" trials. In the No Scanning Condition we again found that the means for the near-close and near-far probes were significantly different, $F(1, 10) = 11.34$, $p < .01$; when probes at the three distances were analyzed, distance again was significant (with means of 1364, 1543, and 1815 msec for near-close, near-far, and far trials, respectively), $F(2, 20) = 19.59$, $p < .0001$. In addition, visually complex letters required more time than visually simple ones (1336 vs. 1574 msec), $F(1, 10) = 6.23$, $p < .05$.

The No Scanning data were also analyzed using a regression analysis identical to that reported above. Now, however, the first variable entered into the equation was the number of segments to the second probe from the beginning of the letter, $r = .78$, $p < .01$; no other variable contributed significantly to the variance accounted for, $p > .1$ in all cases, and the overall multiple R was .86. This result again supports the claim that letters are imaged a segment at a time. This group evinced generally longer response times than the corresponding between-subjects group (a mean of 1455 msec, compared to 1238 msec for the former group), which suggests that these subjects may not have had the first segment imaged by the time the probes appeared; if so, then it makes sense that the number of segments from the beginning of the letter was highly correlated with response times.

The Scanning Condition data also revealed that the means for near-close and near-far trials were significantly different, $F(1, 10) = 18.67$, $p < .002$; when the three distances were analyzed, distance was again significant, $F(2, 20) = 20.78$, $p < .0001$. However, there now was an interaction of letter with distance, $F(2, 20) = 14.72$, $p < .0002$: the means for near-close, near-far and far probes for J were 1750, 1813, and 1932 msec, and for G were 1548, 1868, and 2379 msec. The differences for the different distances for J are substantially less than those for G. This interaction makes sense because the actual distances to the second probe were greater for the letter G, as is evident in Figure 4. We analyzed the data from the two conditions together to compare the relative effects of probe location. There was no difference in the effects of probe location in the two conditions, $F < 1$. In addition, in another analysis we again found that more time was required for more complex letters (1273 vs. 1882 msec), $F(1, 10) = 120$, $p < .0001$. A separate analysis revealed that this effect was more pronounced than that observed in the No Scanning Condition, $F(1, 20) = 11.32$, $p < .005$, for the interaction of Condition and Complexity;

the within-subjects design did indeed prove more sensitive to this difference than had the between-subjects design.

The scanning data were also considered using stepwise regression analyses. The first variable to enter the equation was the number of segments from the beginning of the letter to the second probe mark, $r = .94$, $p < .01$. However, the distance to the second probe was the second variable entered and contributed significantly to the variance accounted for, $F(1, 16) = 7.77$, $p < .03$. This result indicates that both the generation and scanning effects contributed to overall response times. No other variable contributed significantly to the variance accounted for, $p > .1$, and the overall multiple R was .96.

Discussion

The regression analyses revealed clear effects of distance when the subjects were asked explicitly to scan their images when searching for the probe marks. Thus, the measure is not insensitive to scanning effects, and it is noteworthy that the regression analyses again demonstrated that distance is not an important factor when subjects are not told to scan. Scanning could not have been used generally in the No Scanning Condition, or distance would have correlated significantly with the times as it did in the Scanning Condition.

The results of the regression analyses again suggest that images of letters are constructed from segments in the same sequence as they are hand printed. The subjects in the between-subjects experiment apparently could generate the initial segment in the time available before the probes appeared, whereas the subjects in the within-subjects experiment apparently could not. This finding is consistent with the overall faster times from the subjects participating in the between-subjects condition. The results showed that subjects image each line segment in the matrix as a distinct part; the sheer number of filled squares did not prove to be an important correlate of generation time. In addition, the present results replicated our earlier effect of complexity, even though the experimenters were completely ignorant of the predictions and purposes of the experiment.

We also found that more time was required for near-far probes than for near-close ones, which was a reliable difference in both of our No Scanning Condition groups; indeed, these effects were of the same magnitude as those observed in the Scanning Condition groups. These probes were on a single segment, and suggest that some scanning did indeed occur even when scanning instructions were not given. This scanning apparently was restricted to selected segments of an image, and might have been used in either image generation or in post-generation inspection. However, we do not know whether this scanning is functional. That is, it could be an essential process in placing or examining segments in precise positions in an image, or it could have no actual role in the task. The following experiment is designed in part to investigate the functional role of scanning in image generation.

Experiment 3

The most straightforward interpretation of the results of Experiment 2 is that subjects did in fact scan selected parts of their images, either during or after image generation. This conclusion is supported by the effects of the position of a probe along a segment; however, the failure of distance to account for significant amounts of variance in the regression analyses of the No Scanning Conditions indicated that scanning was not a pervasive part of processing in this task. The present experiment was designed to investigate whether scanning plays a functional role in image generation. If so, then when scanning is impaired, image generaton should be more difficult.

In this experiment we asked subjects to fixate at the center of the screen immediately after reading the cue. Subjects were to remain fixated on the center of the screen during the image generation and inspection processes. We assume that forcing fixation on the center of the screen should impair attentional scanning to other locations. Thus, if scanning was a critical contributor to our earlier effects, those effects should be altered by these instructions. In particular, if the complexity effect in fact reflects the time to position individual parts in an image, and scanning is an important process used in positioning parts, then the complexity effect should be amplified when scanning is impaired (and it is more difficult to position each segment).

Method

Subjects

Twelve Harvard University undergraduates participated as paid volunteers. None of these subjects had participated in the previous experiments. The experimenter was again ignorant of the purposes and predictions of the experiment.

Materials

The stimuli used in Experiment 2 were also used here. In addition, a 3 mm round piece of masking tape was affixed to the location on the screen corresponding to the center of the grid. This tape was used as the fixation point.

Procedure

Subjects were told to read the lower case cue and then immediately fix their attention on the tape. They were urged to maintain fixation on the tape, throughout the task. Posner, Nissen and Ogden (1978, pg 149) demonstrated that subjects are very good at following this kind of fixation instruction; indeed, anticipatory eye movements of 1 degree or more occurred on only about 4% of their trials. We took Posner et al's results as evidence that extensive monitoring of eye fixation was not necessary. Nevertheless, during the practice trials the experimenter watched the subjects' eyes and ensured they remained fixated on the center of the screen; during the actual test trials the experimenter was out of sight, to eliminate potential experimenter effects (even though--as before--the experimenter was ignorant of the purposes and predictions of this experiment). Aside from the addition of the instructions to fixate on the tape, the instructions were identical to those used in the No Scanning Condition of Experiment 2. As before, 8 practice trials preceded the actual test trials, and subjects were told to respond as quickly and accurately as possible while following instructions.

Results

As usual, simple letters were evaluated more quickly than more complex ones (1105 vs. 1506 msec), $F(1, 11) = 14.26$, $p < .005$. This result demonstrates that the effect of complexity cannot be due to scanning over the image, given that all subjects reported complying with the fixation instructions at least 80 per cent of the time when queried after the experiment proper. No other effects or interactions were significant in this analysis, $p > .25$ in all cases.

To discover whether there were any effects of scanning, we next analyzed only the two near probes. This analysis indicated that the difference between the two near probe locations did not even approach significance, $F < 1$. This result is exactly as expected if the instructions did in fact discourage the subjects from scanning.

We next analyzed the effects of the three probe locations along the letters. This analysis revealed only one significant effect, of increasing distance, $F(2, 22) = 7.85$, $p < .003$. The means were 1293, 1350, and 1876 msec for near-close, near-far, and far probes, respectively. Thus, we again found our effect of segment, with the "far" probes requiring more time than the two "near" ones, which were not significantly different from each other.

The data were also considered using a stepwise regression analysis, exactly as was used in Experiment 2. The first variable to enter the equation was the number of segments between the two probes, $\underline{r} = .87$, $p < .01$. The second variable to enter the equation was the number of filled squares in the entire letter, which also accounted for a significant portion of the variance, $F(1, 16) = 10.26$, $p < .01$. Distance contributed no additional variance whatsoever, $F < 1.1$ for all measures of distance. The multiple R for the equation after all variables were entered was .94.

The data from this experiment were next compared to the data from the between-subjects No Scanning Condition of Experiment 2. Most important, the analysis of variance revealed that the effects of complexity were the same in both experiments, $F(1, 22) = 1.18$, $p > .25$, for the interaction of Condition and Complexity. Indeed, the overall mean response times were the same in both experiments, $F < 1$. These null effects suggest that scanning was not an important component of processing in the previous No Scanning Condition. The data were not simply noisy; this analysis did reveal significant effects of Complexity, $F(1, 22) = 24.74$, $p < .0001$, and Letter, $F(2, 44) = 3.53$, $p < .05$.

A further analysis considered the relative effects of probes at the three locations in the Fixate Condition and No Scanning Condition. As usual, we obtained an effect of distance, $F(2, 44) = 17.68$, $p < .0001$. There was no interaction between Distance and Condition, $F(2, 44) = 1.56$, $p > .20$. Nor was there an interaction between Distance and Condition when only the two near probes were considered, $F(1, 22) = 2.02$, $p = .17$. This failure to find interactions with Condition is not surprising; the original effect was not very pronounced. These results are illustrated in Figure 7.

INSERT FIGURE 7 ABOUT HERE

The error rates for this experiment can be seen in Table 1. There is no evidence of speed-accuracy tradeoffs. The high error rate for far probes for G is due to the fact that there were only 4 such trials for each subject and 2 subjects missed 3 of the 4 trials.

Discussion

The data from the Fixate Condition were very similar to the results from the No Scanning Condition of Experiment 2. Now, however, we did not find a significant difference between the two "near" probe locations, corroborating our assumption that the fixation instructions would discourage scanning. The mere fact that subjects could perform this task as well as before, when scanning was not impaired, is important, suggesting that scanning is not an essential component of image generation. Also important is the finding that the effect of complexity was the same in both conditions. On the one hand, if time to generate images of individual segments is facilitated by scanning, we would have expected more pronounced effects of complexity when scanning was impaired. On the other hand, if images are generated very quickly but more post-generation scanning occurs when when one forms images of more complex letters, and this processing is at the root of the effects of complexity, then we would expect less pronounced effects of complexity when scanning is discouraged. But we did not find either deviation from the results obtained earlier, when subjects were not asked to fixate on a central point during the task. The fact that the number of segments between the two probes proved to be the most important variable in the regression analysis also serves to attest to the importance of segments--and not distance or simple number of intervening squares—in the generation process.

Finally, it may be worth noting that the present results allow us to reject yet another alternative interpretation of our findings. The results cannot be due to eye movements. That is, the increases in time for increasingly complex letters or farther probes cannot reflect the time required to make additional eye movements. This notion is implausible on the face of things, given the magnitudes of our effects relative to eye movement time, but it is worth having the convergent evidence from the fixation condition.

General Discussion

The results from these experiments allow us to draw three general conclusions. First, and perhaps most important, the earlier subjective technique for measuring image generation received a good measure of face validity. We found very similar effects of the complexity of a letter on the time to generate an image of it using a simple self-report task and on our objective measure. Furthermore, the results of the second and third experiments showed that the objective estimate was not due to experimenter-effects, which indirectly demonstrates that the subjective self-report task was not affected by any possible experimenter-effects in our first experiment. Thus, the previously reported results from experiments that used the subjective method are unlikely to lead us too far astray. Second, we showed that images are generated a segment at a time. Although there was evidence that subjects may spontaneously scan selected parts of a pattern being imaged, we found that such scanning did not have a functional role in image generation; the complexity effect or the longer times to judge probes positioned on more removed segments were not a consequence of scanning. The finding of increased time to verify probes that fell on more removed segments in the Fixation Condition--with no hint of an effect of distance per se--shows that the effect of segment is not due to subjects' scanning an image while generating it or after generating it. Third, there is evidence that the segments of a letter are imaged in the same order in which they are usually hand printed.

In Experiment 2, we found significant effects of distance from near-close to near-far probes on the same segment. As it happens, the segments selected for these probes were at "kinks" in the shape; that is, the segments we selected for the two types of near probes were at regions of great change in the contours. Given that distance did not affect times in general, it seems as if subjects tend to scan only when high precision is required to generate or inspect the parts. Perhaps even though the images are generated a segment at a time, the subjects in effect slow down and "look at" the complicated areas of a figure before making a decision. Although we found no evidence in these experiments that this scanning process is actually helpful in image generation or inspection, it is possible that this process does have a useful role in some situations.

The present results are interesting in light of Kosslyn, Holtzman, Farah & Gazzaniga's (1984) recent finding that the right hemispheres of split-brain patients have difficulty in forming images of letters and in imaging the correct relative relation of two parts of an object, whereas their left hemispheres have no difficulty in these tasks. If upper case letters are imaged a segment at a time, it makes sense that the right hemisphere will have difficulty imaging letters: these patients have difficulty performing numerous sequential-processing tasks in their right hemispheres, such as drawing simple inferences about the next item in a progression of successive cues. In contrast, both hemispheres were equally good at imagery tasks requiring the generation of a single "global" shape. The distinction between the two types of tasks suggested that the deficit was specific only to imagery tasks that involved integrating separate units into a single composite form. Thus, these results converge nicely with the claim that letters are imaged a segment at a time.

In conclusion, the present methodology offers promise of helping us to discover further details about how visual mental images are generated. In particular, it could be used easily to study the principles that underlie the order in which parts are added to an image in different task-contexts. Although the earlier methods do not seem to have led us astray, the new one provides opportunities to answer questions that could not be grappled with before.

Footnotes

Requests for reprints should be sent to S. M. Kosslyn, 1236 William James Hall, 33 Kirkland Street, Cambridge, MA 02138. This work was supported by NIMH Grant MH 39478-01 and ONR Contracts N00014-82-C-0166 and N00014-83-K-0095. The authors wish to thank Eric Domeshek and Jeffrey Holtzman for useful criticism, and Lori Cronin, Tim Doyle, Phil James and Leah Kaufman for technical assistance.

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Table 1. Error Rates (in percentages). When appropriate, errors for complex letters are broken into near-close (NC), near-far (NF), and far (F) probe locations.

Experiment 1

Stimulus	Task: Brief Delay	Perceptual (within-subjects)	Perceptual (between-subjects)	Image Inspection
L	2.5	.8	2.5	.8
C	5.8	.8	1.7	3.3
J - Near	6.7	1.7	0	0
J - Far	10.0	0	0	3.3
G - Near	1.7	3.3	1.7	0
G - Far	5.0	5.0	1.7	0

Experiment 2

Stimulus	No Scanning Instructions		Scanning Instructions	
	Between-subjects	Within-subjects	Between-subjects	Within-subjects
L	2.8	1.0	.93	1.0
C	1.8	0	2.8	0
J - NC	2.8	3.0	1.4	1.5
J - NF	4.2	9.1	1.4	7.6
J - F	8.3	6.8	4.2	2.3
G - NC	0	3.0	1.4	3.0
G - NF	0	1.5	2.8	4.5
G - F	12.5	18.2	2.1	2.3

Table 1 (continued)

Experiment 3

Stimulus	
L	2.8
C	6.5
J - NC	4.2
J - NF	5.6
J - F	6.2
G - NC	1.4
G - NF	1.4
G - F	20.8

Figures

Figure 1. The simple and complex stimuli used in Experiment 1, with probe locations.

Figure 2. Mean response times for simple and complex letters in Experiment 1, for image generation, image inspection, and perceptual inspection.

Figure 3. Mean response times for near and far probe locations in Experiment 1.

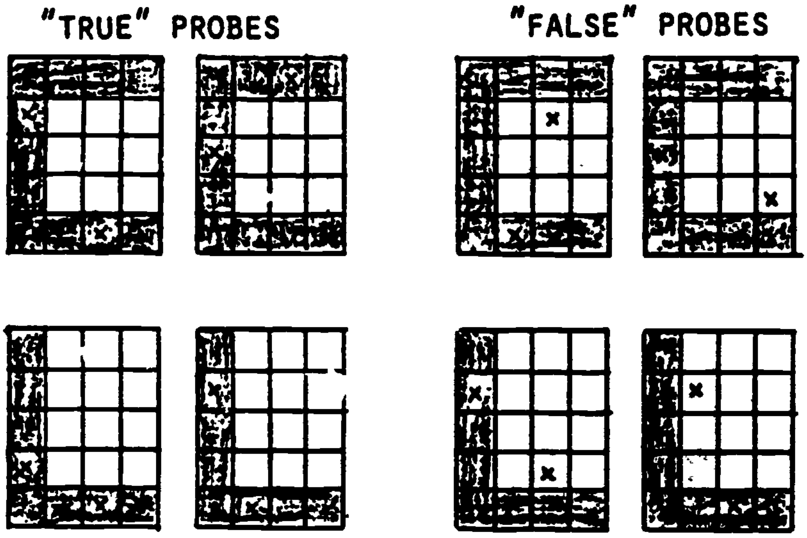
Figure 4. The two types of near probe locations used in Experiments 2 and 3.

Figure 5. Mean response times for three types of probe locations in Experiment 2.

Figure 6. Mean response times for simple and complex letters in Experiment 2.

Figure 7. Mean response times in Experiment 3. The right panel presents the means from the three probe locations used for the complex letters.

SIMPLE STIMULI



COMPLEX STIMULI

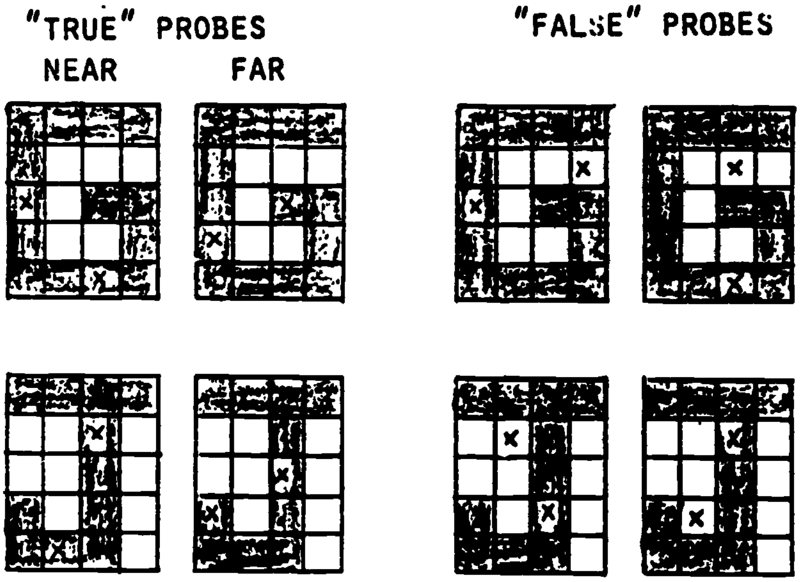


FIGURE 2

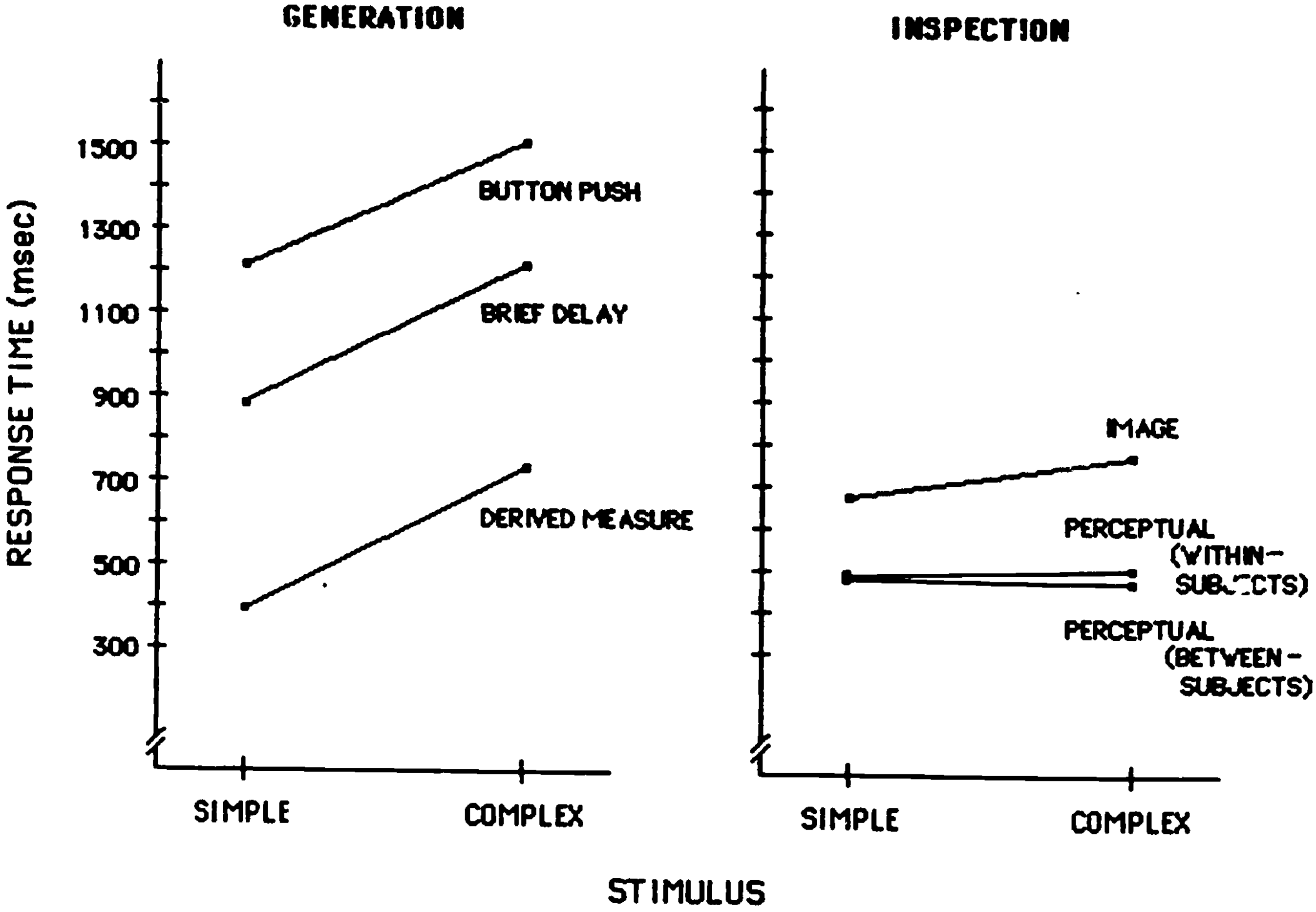
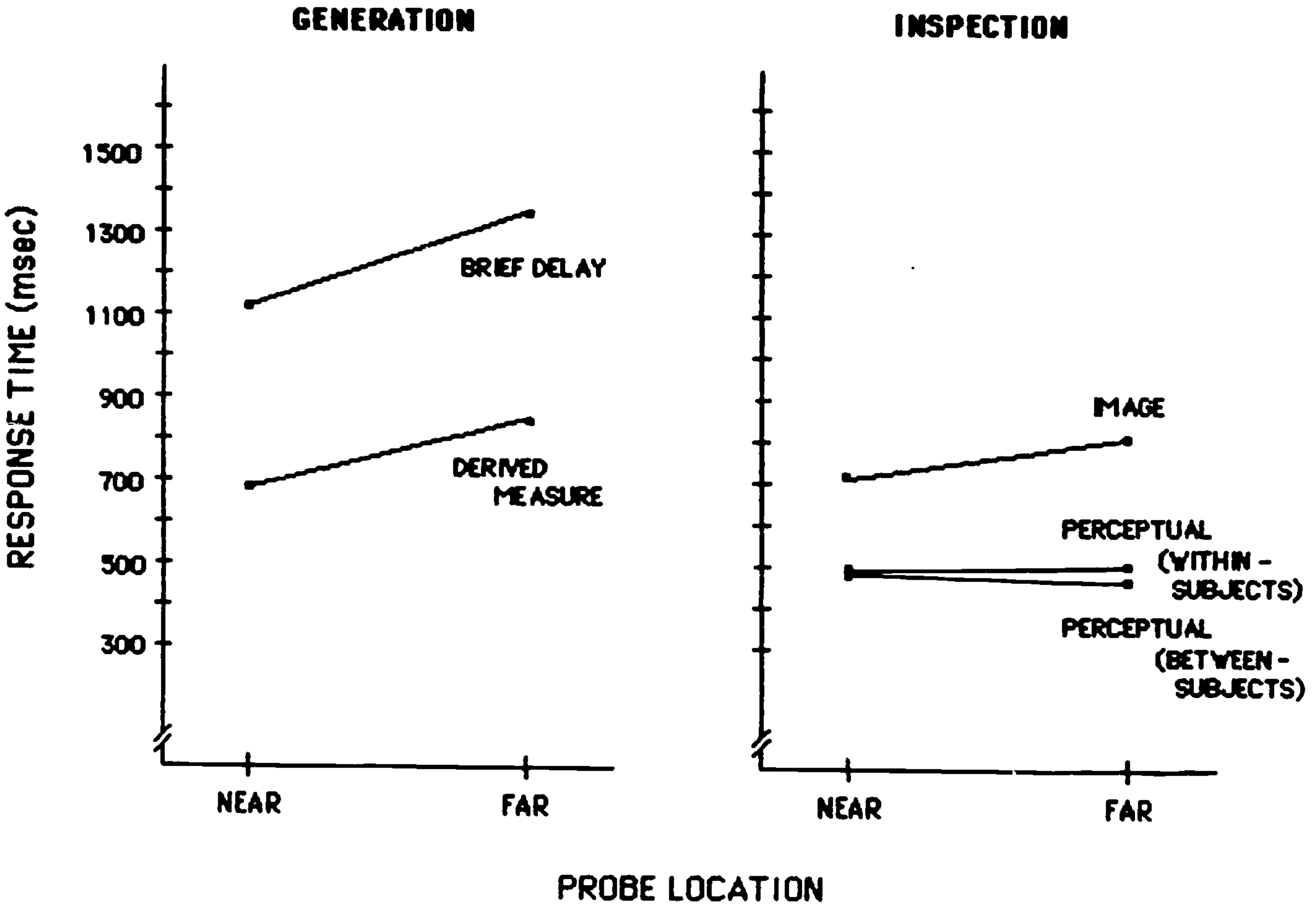
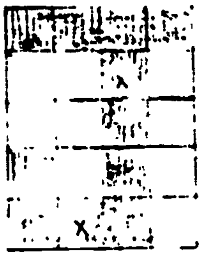
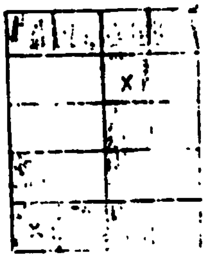

GENERATION
INSPECTION
RESPONSE TIME (msec)
1500
1300
1100
900
700
500
300
BUTTON PUSH
BRIEF DELAY
DERIVED MEASURE
IMAGE
PERCEPTUAL (WITHIN-SUBJECTS)
PERCEPTUAL (BETWEEN-SUBJECTS)
SIMPLE
COMPLEX
SIMPLE
COMPLEX
STIMULUS

FIGURE 3

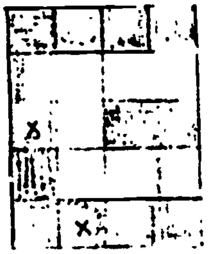

GENERATION
INSPECTION
RESPONSE TIME (msec)
1500
1300
1100
900
700
500
300
BRIEF DELAY
DERIVED MEASURE
IMAGE
PERCEPTUAL (WITHIN-SUBJECTS)
PERCEPTUAL (BETWEEN-SUBJECTS)
NEAR
FAR
NEAR
FAR
PROBE LOCATION



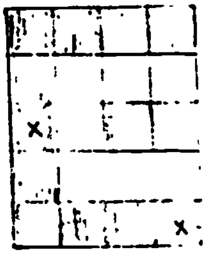
Near-close J



Near-far J



Near-close G



Near-far G

FIGURE 5

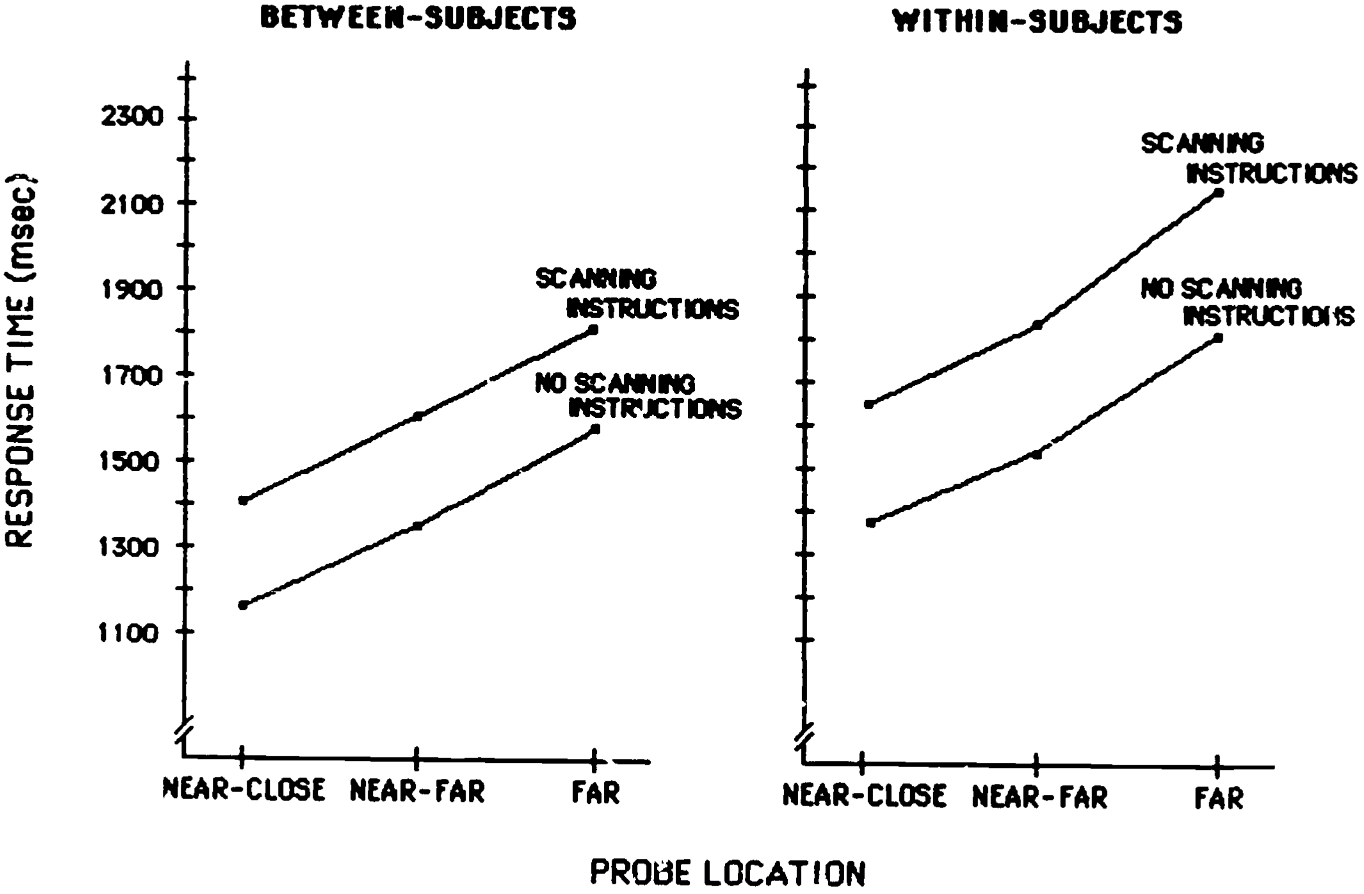

BETWEEN-SUBJECTS
WITHIN-SUBJECTS
RESPONSE TIME (msec)
2300
2100
1900
1700
1500
1300
1100
SCANNING INSTRUCTIONS
NO SCANNING INSTRUCTIONS
NEAR-CLOSE
NEAR-FAR
FAR
PROBE LOCATION

FIGURE 6

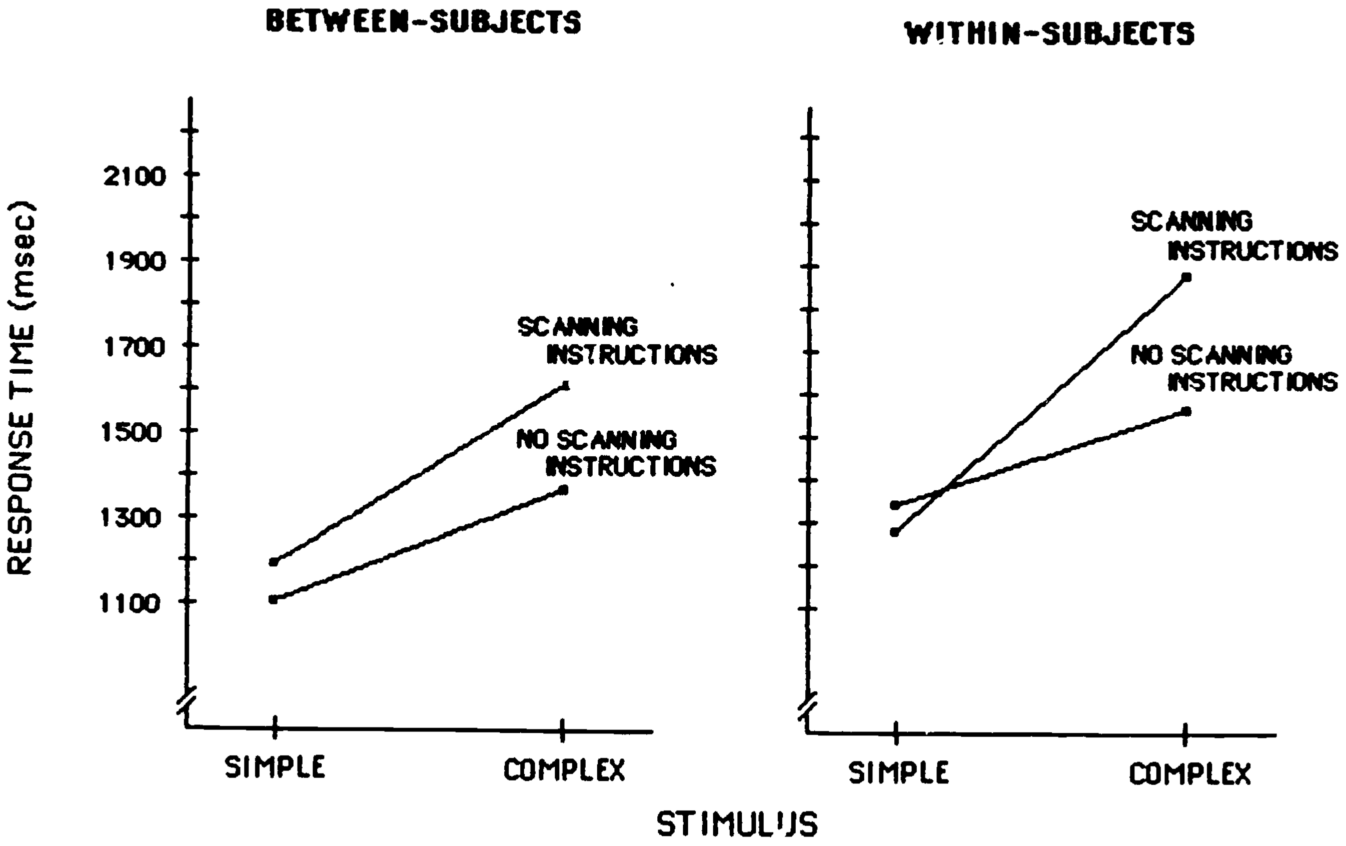
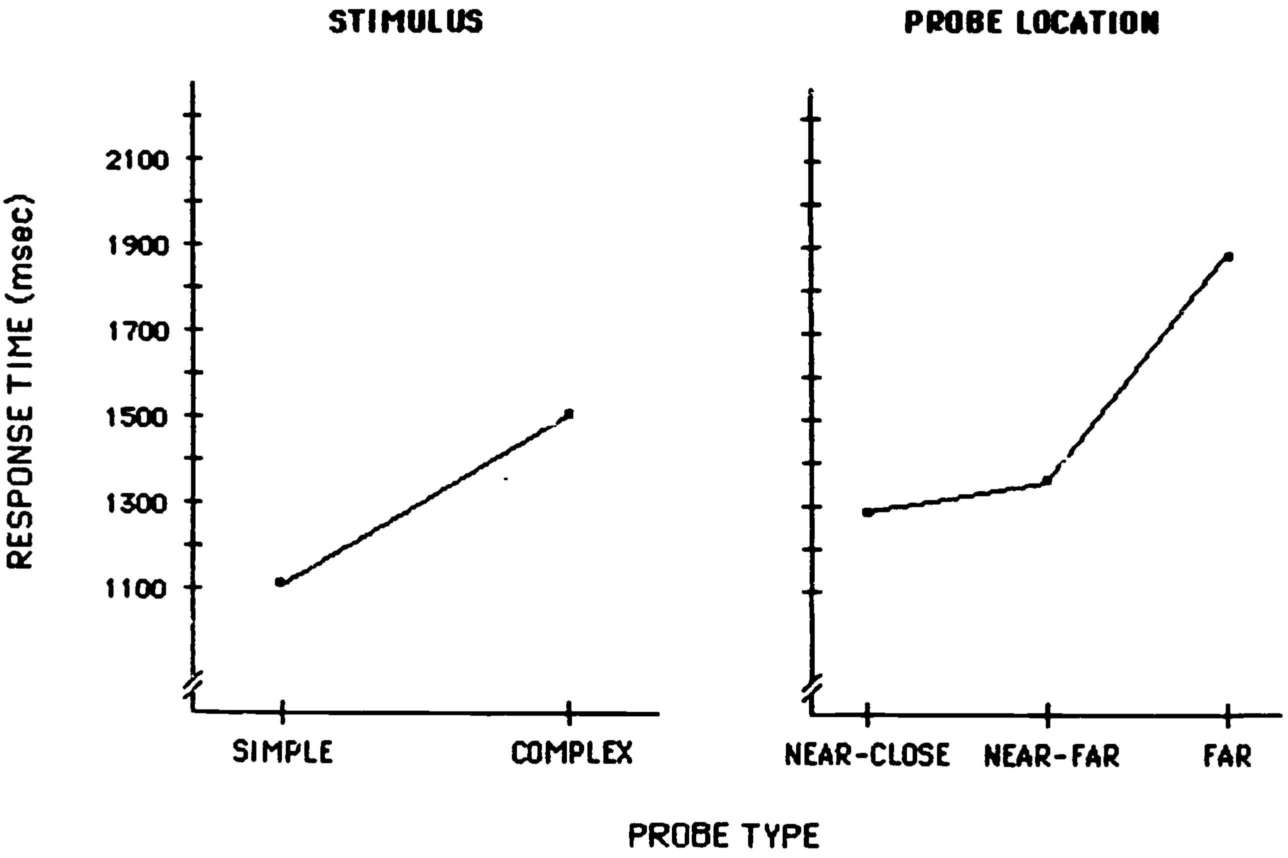

BETWEEN-SUBJECTS
WITHIN-SUBJECTS
RESPONSE TIME (msec)
2100
1900
1700
1500
1300
1100
SCANNING INSTRUCTIONS
NO SCANNING INSTRUCTIONS
SCANNING INSTRUCTIONS
NO SCANNING INSTRUCTIONS
SIMPLE
COMPLEX
SIMPLE
COMPLEX
STIMULUS

FIGURE 7


STIMULUS
PROBE LOCATION
RESPONSE TIME (msec)
2100
1900
1700
1500
1300
1100
SIMPLE
COMPLEX
NEAR-CLOSE
NEAR-FAR
FAR
PROBE TYPE

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