Memory & Cognition
2006, 34 (3), 475-490

Different cognitive processes in two image-scanning paradigms

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Mental image scanning is generally assumed to be a single process that allows people to shift attention across visualized objects. However, this implicit assumption is open to question. We report a set of three experiments based on the tasks originally designed by Kosslyn, Ball, and Reiser (1978) and Finke and Pinker (1982). Participants scanned the identical images of an array of dots in the two tasks. Nevertheless, the participants required more time to shift their focus over the imaged stimulus in the Kosslyn et al. (1978) paradigm. Moreover, correlational analyses revealed no consistent relationship between the slopes of the increases in scanning times with increasing distances in the two paradigms. We conclude that in the Kosslyn et al. (1978) paradigm, the participants draw primarily on transformational processes to scan, whereas in the Finke and Pinker (1982) paradigm, they draw primarily on attentional processes. Both processes, transforming the image and shifting an attention window, produce linear increases in time with increases in distance, but for different reasons.

Research on mental imagery over the past 20 years has two interesting overarching characteristics. The first is the genuine gains in our empirical knowledge of this form of representation. Today, there are few disagreements about the empirical facts regarding mental imagery, even when the interpretation of some of them remains a matter of controversy (Kosslyn, Ganis, & Thompson, 2003; Pylyshyn, 2002). The second characteristic is that the study of mental imagery not only has benefited from classic experimental methodologies, but also has sparked the creation of new paradigms. The present research builds on previous discoveries about how visual mental images are processed and focuses on paradigms created to study such processing. Specifically, we ask whether two paradigms designed to study mental image scanning in fact tap the same underlying processes; if not, this phenomenon is more complex than is often assumed.

S.M.K. was supported by ROLE Grant REC-0106760 from the United States National Science Foundation and Grant 5 R01 MH60734-03 from the National Institutes of Health. The authors are grateful to Colin M. MacLeod, Timothy Hubbard, and two anonymous reviewers for helpful suggestions on the first version of the manuscript. Correspondence concerning this article should be addressed to G. Borst, Groupe Cognition Humaine, LIMSI-CNRS, Université de Paris-Sud, BP 133, 91403 Orsay Cedex, France (e-mail: gregoire.borst@limsi.fr).

Note—This article was accepted by the previous editorial team, when Colin M. MacLeod was Editor.

The first image-scanning paradigm was developed to investigate the spatial properties of images (Kosslyn, 1973). In the original experiment, participants memorized drawings of elongated objects (such as a tower). Afterward, they were asked to close their eyes, visualize one of the drawings, and mentally focus at one end of the depicted object (e.g., the bottom of the tower). Then they heard the name of a possible part or property of the imaged object (a clock on the façade, a flag on the roof, etc.) and were to "look for" it (keeping their eyes closed). In this task, the participants were never told to scan over the object in the image but, instead, were told that they needed to focus on the original location until the probe was delivered and then to focus on the named part or property (if they could find it on the imaged object). When they had focused on the named part or property—or the region where it should have been if it had been present, when it had not, in fact, been included on the drawing—they pressed one of two buttons. If they were able to focus on the named part or property (because it had been included in the drawing), they pressed one button; if they were focused on the appropriate location but the named part or property was not present, they pressed the other button. Three different distances separated the point of initial focus and the location of the named part or property, and the longer the distance, the more time the participants took to respond. This finding was taken as evidence that distance, as traversed by image scanning, is represented in visual mental images.

A variation on this first image-scanning paradigm was later used by Kosslyn, Ball, and Reiser (1978). The new features were that focus and probe locations did not have intervening objects, 21 distinct distances were traversed, and attention needed to be shifted over two dimensions. Kosslyn et al. (1978) designed a map of an island containing seven landmarks (a beach, a rock, etc.) located in such a way that the distances between all the pairs of landmarks were distinct. In the learning phase, the participants memorized the map of the island. In the test phase, they heard the name of one of the seven landmarks at the beginning of each trial and were to form an image of the entire island with all the landmarks and to focus mentally on the named object. Shortly thereafter, the name of a second landmark was presented. If that object was one of the landmarks present on the map, the participants were to scan to it and press a button when reaching it. If they "looked" and did not "see" it (and they were told that if it had been included on the map, they should be able to "see" it), they were to press another button. As in the original experiment, the participants required more time to scan greater distances, and in fact, scanning times increased linearly with increasing distances. Kosslyn et al. (1978) interpreted this result as evidence that mental images incorporate the metric information present in the original stimulus. The result was replicated in a variety of subsequent experiments, including those in which the mental image of the configuration was constructed on the basis of verbal descriptions (e.g., Denis & Cocude, 1989, 1992; Denis, Gonçalves, & Memmi, 1995).

Following the initial studies, other researchers criticized the experimental procedures and paradigms. The first criticism was that the experimental situations were contaminated by demand characteristics (Intons-Peterson, 1983; Mitchell & Richman, 1980). One criticism focused on experimenter expectancy effects: In this view, participants deduced the investigator's expectations and controlled the timing of their responses in order to be consistent with these expectations. A second criticism had nothing to do with experimenter expectations but centered on the notions of task demands and tacit knowledge (Pylyshyn, 1981). According to this view, the very nature of the task implied that participants should imitate what they thought they would do in the corresponding perceptual situation (which was the task demand), and they had the tacit knowledge to be able to do this. Both sorts of counterexplanations claimed that the scanning results said nothing about the nature of the mental representations that underlie imagery and, instead, reflected only how the participants (consciously or unconsciously) chose to regulate their responses during the experiment.

Such criticisms were very useful in that they forced imagery researchers to improve the design of their experiments. In particular, two conditions had to be met in order to rule out such methodological counterinterpretations. First, the participants should not be able to infer that the experimenter was interested in the relationship between time and distance. Second, the task could not incorporate task demands that led the participants to believe that they should mimic perception. Clearly, asking participants to form and scan images was not satisfactory.

Finke and Pinker (1982) were the first to design an image-scanning paradigm that satisfied these conditions. In their paradigm, the participants first memorized a pattern of four dots. This pattern was then replaced by an arrow in an unexpected location in a blank field. The participants were to decide as quickly as possible whether the arrow was pointing to a location previously occupied by one of the dots. The participants were not instructed at any time to form or scan visual mental images. However, the results revealed a strong linear relationship between response times (RTs) and the distances separating the tip of an arrow and a target dot, very much like the one found in the experiments using the original paradigm. The results could not be explained by experimenter expectancy effects or task demands. These findings were confirmed in subsequent experiments (Finke & Pinker, 1983; Pinker, Choate, & Finke, 1984) and were taken as strong support for the claim that scanning reflects the spatial structure of image representations.

Since then, the process of image scanning has been investigated in a variety of further experimental paradigms (Dror & Kosslyn, 1994; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; for a review, see Denis & Kosslyn, 1999). All of these tasks were implicitly assumed to tap a single process, image scanning, that allows people to shift their attention across objects in visual mental images. However, such an implicit assumption is open to question. Many different processes could produce the time/distance linear relationship. On the one hand, for example, Kosslyn (1980) conceived of image scanning as a type of image transformation, where the imaged object was "slid" across a spatial structure, the "visual buffer," so that different parts were in the central, high-resolution portion. On the other hand, Pinker (1980) suggested that under some circumstances, scanning was accomplished by shifting an internal locus of attention, much like the sort of covert attention shifting documented by Posner and his colleagues (e.g., Posner, Snyder, & Davidson, 1980). Indeed, Pinker suggested that scanning may often involve both transformation and attentional-shifting processes.

It is possible that different paradigms draw on the different processes to different degrees or use yet other types of processing. The present study was designed to discover whether scanning should be decomposed into (at least) two distinct subtypes. We compared scanning in the two classic paradigms—that of Kosslyn et al. (1978) and that of Finke and Pinker (1982), respectively. The same participants were tested in the two paradigms. We sought to discover whether the same chronometric regularities would appear in both paradigms. Specifically, we investigated whether parameters of performance in the two paradigms are correlated: Do participants who scan relatively quickly in one paradigm also scan quickly in the other? If the same underlying process is being tapped, we would expect high correlations between the slopes of the time/distance regression lines. In contrast, if different processes are tapped, we would not expect such high correlations.

EXPERIMENT 1

In the first experiment, participants performed the two image-scanning tasks. Our first objective was to replicate the classic results obtained in the two paradigms. After this, we investigated the relationship between the participants' performance in the two tasks. The experiment was also intended to provide us with information on the components of working memory that contribute to image scanning. To this end, we also assessed performance in a verbal and a spatial working memory task (Cohen et al., 1994).

In order to compare the results obtained in the two scanning tasks, we matched every aspect of the two procedures. First, to circumvent the problem resulting from the fact that the material in Kosslyn et al.'s (1978) experiment included seven points, whereas the material in Finke and Pinker's (1982) experiment included only four points, we created a single pattern for the two tasks with the same number of points. We used the same configuration of dots, as well as the same set of interdot distances. Because each participant received two scanning tasks, rather than using a different pattern, we used a configuration in one task and its 180º rotated version in the other task.

In both tasks, the stimulus configuration contained five dots of different colors. In the Kosslyn et al. (1978) task (hereafter referred to as the *KBR task*), the participants mentally scanned between the 10 possible pairs of the five dots of one pattern. In the Finke and Pinker (1982) task (hereafter referred to as the *FP task*), on each trial, the participants decided whether an arrow pointed at the location occupied by one of the previously seen dots. In both tasks, we recorded RTs and expected them to increase with increases in distance. We were interested primarily in the relationship between the individual slopes of the best-fitting lines in the two tasks.

The participants also completed two working memory tasks. We administered these tasks because the results from some previous studies have suggested that visual imagery draws on more general visual information processing resources (Logie, 1986; Quinn & McConnell, 1996). However, the exact relationship between visual imagery and visuospatial working memory is still debated (cf. Cornoldi, Logie, Brandimonte, Kaufmann, & Reisberg, 1996; Cornoldi & Vecchi, 2003; Logie, 1995). The two working memory tasks were variants on an *n*-back task procedure (Cohen et al., 1994; Gevins & Cutillo, 1993). In the verbal working memory task, the participants decided whether each newly presented letter was the same as the one presented two trials previously. In the spatial working memory task, the participants made the same decision for the locations of black dots.

Method

Participants

Sixteen undergraduates from the Institute of Psychology of René Descartes University participated as unpaid volunteers in the experiment (8 men and 8 women). Their average age was 20 years 5 months. Twelve were right-handed, and 4 were left-handed. Data from 2 additional people were not analyzed because they reported having followed the instructions less than 75% of the time in at least one of the two scanning tasks.

Materials and Procedure

The participants were informed, upon arrival in the testing room, only that they were about to take part in a study of visual perception and visual memory. They were tested individually with two computers: one used to present auditory stimuli and the other to display visual stimuli. At the end of the experiment, the participants filled in a questionnaire to ensure that they had not inferred the purpose or predictions of the experiment and that they had followed the instructions at least 75% of the time in each of the two scanning tasks.

Scanning tasks. Two configurations of five colored dots (red, blue, black, yellow, and green), 6 mm in diameter, were created on a white background (see Figure 1). The dots occupied a 14º × 19º portion of the visual field of the participants, who were sitting in front of the computer screen on which the dots were displayed. The second pattern was a 180º-rotated version of the first. Each distance between all 10 pairs of dots was at least 0.7 cm longer than the next shortest one (ranging from 1.5 to 15 cm).

The KBR task. Pairs of color names were recorded on a computer. These stimuli consisted of pairs of names of the colors of the five dots in the display, as well as the name of each of those colors paired with the name of one of four additional colors (gray, pink, white, and brown). All of the names used contained a single pronounced syllable in French. Each of the five colors of dots present in the stimulus was named 16 times as the first member of the pair, followed 5 sec later by the name of another color. On 8 of those trials, the second name was one of the four other colors present in the display, and on the remaining 8 trials, it was one of the four other colors. Every pair of color names occurred 4 times; the two that included colors in the configuration were counterbalanced, so that each member appeared first one time. The order of pairs was randomized, except that no

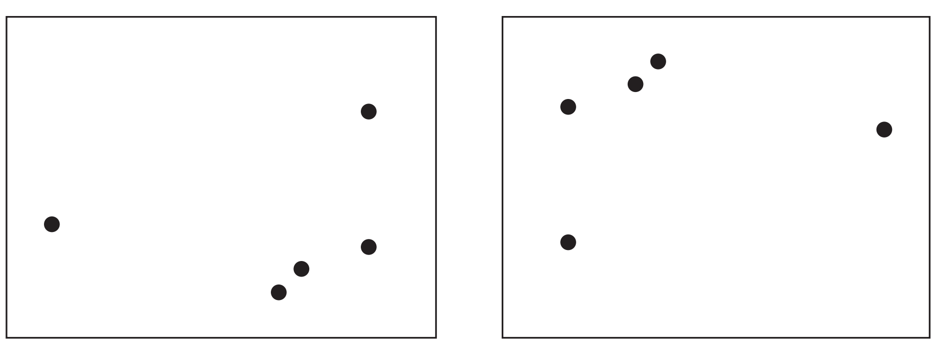

Figure 1. Patterns used in the two image-scanning tasks (originals in color).

more than 2 *yes* trials (pair of names where the second color named a dot in the configuration) could occur in a row. Presentation of the second color name started a clock, which was stopped when the participant made a response. A new trial began 6.5 sec after the second color had been named. The participants first received 4 practice trials (2 *yes* and 2 *no* trials) before the two blocks of 40 test trials.

In the *learning phase*, the participants memorized the exact locations of the five colored dots. First, they were told to study the pattern of five dots, close their eyes, and form a mental image of the pattern. Then they opened their eyes and compared their mental image with the actual pattern of dots, correcting their image. They repeated this procedure until they thought that their image was accurate. The pattern of dots was then removed, and the participants drew the exact location of each dot on a blank page with the corresponding color. Following this, they compared their drawing with the original. This draw-and-study procedure was repeated until all dots were within 0.3 cm of their actual respective locations. Depending on the participants, from two to six drawings were required to reach this criterion.

In the *test phase*, the participants were informed that on each trial, they would hear the name of one of the colored dots. At this time, they were to visualize the entire pattern of dots and mentally focus on the named one. Five seconds later, they would hear the name of a second color. If this word named one of the dots in the pattern, they were to scan to that dot and press a button with their dominant hand when they reached the center of it. The scanning was to be accomplished by imaging a small spot moving in a straight line as fast as possible (while still remaining visible) from the first colored dot to the second (this procedure was used in one of the KBR experiments). If the second color word did not name one of the dots in the pattern, they were to press another button with their other hand. The participants were instructed to respond as quickly and accurately as possible. Both RTs and the nature of the responses were recorded.

The FP task. At the beginning of each trial, the pattern of five colored dots was displayed for 4 sec. A blank field was then presented for 2 sec to eliminate any residual iconic image of the pattern. Following this, an arrow, 1 cm in length, appeared on the screen, remaining visible until the participant responded. On half the trials, the arrow pointed at a location previously occupied by a dot, and on half it did not. For the *yes* trials, each of the arrows pointing at the location of one of the dots was located at one of the 10 distances used in the KBR task. In fact, for each dot, we constructed four arrows, one placed near each of the four other dots. For the *no* trials, the arrows "missed" all the five dots by at least 40º.

The participants were told that their task would be to decide, as quickly and accurately as possible, whether the arrow was pointing to a location that had been occupied by one of the previously seen dots. If so, they should press one button with their dominant hand; if not, they should press the other button with their other hand. Then, an example of a *yes* trial was presented by simultaneously displaying the pattern and an arrow pointing at one of the dots. The participants pressed the *yes* button to continue. They were informed that the arrow would either point straight at the center of one dot or miss all the five dots. The participants performed five practice trials (three *yes* and two *no* trials). The computer provided error feedback at the end of each trial. Missed trials were repeated at the end of the practice trials.

Two blocks of 40 experimental trials were then presented. The order of the trials was randomized, except that no more than 2 *yes* or *no* trials could occur in a row. In each block, there were 20 cases in which the arrow pointed at one of the locations previously occupied by a dot and 20 in which it did not. Thus, each distance was represented two times in each block. The presentation of the arrow started a clock, which was stopped when the participant pressed one of the two buttons; RTs and the nature of the responses were recorded.

Working memory tasks. The participants performed a verbal and a spatial working memory task. The task structure was exactly the same for the two tasks. We created three blocks of 19 trials (one practice block and two experimental blocks). On each trial, the participant was presented with a stimulus for 0.5 sec. The stimulus was followed by another 2.5 sec later, and the participant pressed a key if the stimulus was the same as the one *two back* and another key if it was not. The presentation of the stimulus triggered a clock, which was interrupted by the participant's pressing either the *yes* or the *no* button; both the responses and RTs were recorded. The word PAUSE was displayed for 10 sec between each block. The order in which the two blocks of test trials were presented was randomized.

The verbal working memory (VWM) task. The stimuli were letters presented in a 24-point Helvetica font, in upper- or lowercase at random. The letters were selected from a set of 18 consonants and were presented in the center of the screen. The participants were told not to distinguish between upper- and lowercase versions of the letters when making their judgments. This aspect of the design was included in order to encourage the participants to use verbal processes to perform the task.

The spatial working memory (SWM) task. The stimuli were black dots 3 mm in diameter. Each of the dots could be presented at 18 possible locations along the boundary of a virtual circle, one dot every 20º. For each dot, the participants decided whether or not it was in the same location as the dot presented two trials previously.

General procedure. Each participant performed the four tasks (two scanning tasks and two working memory tasks). The order of the two scanning tasks and the assignment of the two stimulus configurations (the two patterns shown in Figure 1) were counterbalanced over participants, as well as the order of the two working memory tasks, which were completed by the participants between the two scanning tasks.

Results

As a first step, we analyzed the error rates (ERs) and the RTs to discover whether we had replicated the earlier findings. Following this, we compared the slopes of the regression lines and the height of the intercepts in the two tasks. We then analyzed performance in the two working memory tasks and considered the relation between such processing and that underlying scanning in both tasks.

Preliminary analyses did not reveal any effect of gender or of the order in which the tasks were performed on the various measures taken. Thus, we pooled over these factors, and they will no longer be mentioned in the report of the results.

Scanning Tasks

ERs. In the KBR task, errors occurred on 0.9% of the trials, a very low figure similar to those reported in previous experiments (Denis & Cocude, 1989; Kosslyn et al., 1978). In the FP task, the participants made errors on 13.4% of the trials. There was no speed–accuracy tradeoff, as was revealed by the lack of correlation between ERs and RTs in the two tasks (see below).

RTs. We analyzed only RTs from correct responses for the *yes* trials, either when the participants reported having mentally scanned the distances between pairs of colored dots (in the KBR task) or when they correctly scanned between the tip of an arrow and a target dot (in the FP task). Prior to the analyses, we eliminated outliers, which were defined as RTs more than two standard deviations from the mean of that condition for that participant. For a given participant, outliers were replaced by his or her mean RT for this distance. Outliers occurred in 2.6% of the trials in the KBR task and 2.4% in the FP task.

The data from the KBR task were submitted to an ANOVA. We first averaged the RTs over trials to obtain a mean for each distance for each participant and then conducted the analysis over participants. We found that RTs varied for the different distances [$F(9,135) = 30.44$, $p < .0005$.] As is shown in Figure 2, the best-fitting linear function, calculated by the method of least squares, revealed that RTs increased linearly with increasing distances [$F(1,15) = 60.59$, $p < .0005$]. The Bravais–Pearson correlation coefficient between times and distances was $r(8) = .89$, $p < .01$. These results replicate those reported by Kosslyn et al. (1978) and Denis and Cocude (1989). The participants therefore appeared to have formed a mental image of the pattern of dots and mentally scanned between each pair of dots.

The same analysis was performed on the data from the FP task. Again, RTs varied for the distance between the arrows' tips and target dots [$F(9,135) = 9.72$, $p < .0001$]. As is evident in Figure 2, the best-fitting linear function, calculated by the method of least squares, revealed that RTs increased linearly with increasing distance [$F(1,15) = 26.08$, $p < .0005$]. The correlation coefficient between RTs and distances was $r(8) = .94$, $p < .01$. These results are consistent with those reported in earlier experiments and suggest that our participants did use image scanning to perform this task.

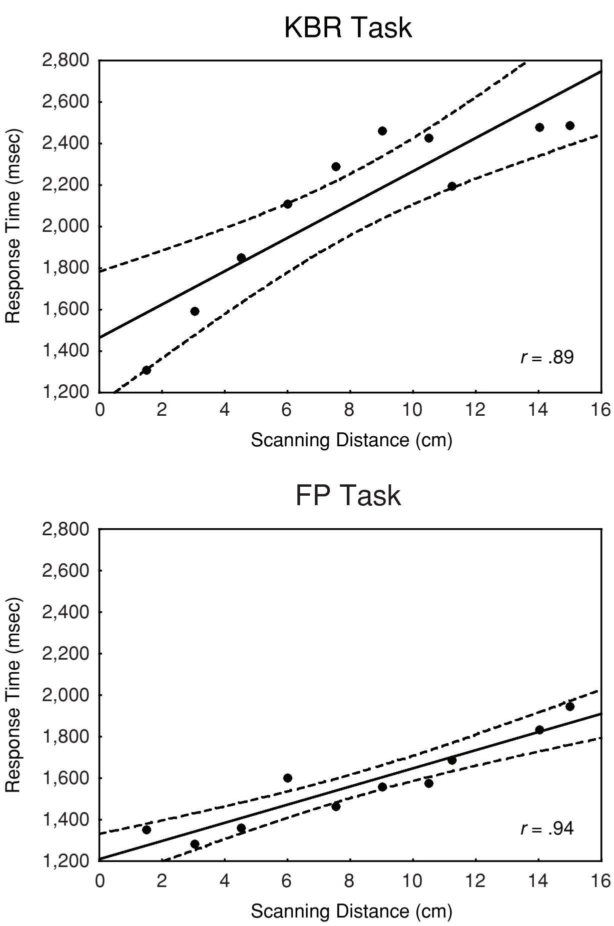

Figure 2. Experiment 1: Time to scan increasing distances in the image-scanning tasks.

The data of primary interest were the slopes in the two tasks. Thus, we calculated the slope of the best-fitting line for each participant in each task. The mean slope in the KBR task ($M = 81$ msec/cm) was significantly steeper than that in the FP task ($M = 52$ msec/cm) [$F(1,15) = 7.66$, $p < .025$]. Thus, the participants scanned more quickly in the FP task.

We also considered the data from both tasks in the same ANOVA and found an interaction between distance and task [$F(9,270) = 5.04$, $p < .0005$]. Overall, the participants required more time in the KBR task ($M = 2{,}125$ msec) than in the FP task ($M = 1{,}569$ msec) [$F(1,15) = 13.03$, $p < .005$]. In addition, an analysis of the intercepts of the best-fitting lines revealed that the KBR task required more time ($M = 1{,}457$ msec) than did the FP task ($M = 1{,}144$ msec) [$F(1,15) = 11.52$, $p < .005$]. The arrow in the FP task told the participants which direction to scan; thus, less time may have been required to initiate scanning in this task.

Working Memory Tasks

We computed the ERs in the two working memory tasks as a measure of the efficiency of working memory. The participants made more errors in the SWM task than in the VWM task [15.8% vs. 5.6%, respectively; $F(1,15) = 20.99$, $p < .0005$].

Correlational Analyses

In order to consider whether the same underlying processes were tapped in the two scanning tasks, we examined the correlations between all the dependent variables. A correlation matrix was calculated on the basis of the participant's individual data. For each participant, we had a total of 10 measures. There were 4 measures for each of the two scanning tasks: (1) the correlation coefficient between RTs and distances, (2) the slope of the best-fitting line, (3) the intercept, and (4) the ER. In addition, we considered the ER in each of the two working memory tasks (see Appendix A).

Among the 45 correlation coefficients, only 4 proved statistically significant. We did find a relationship between the distance/time correlations in the two scanning tasks [$r(14) = .52$], which just reached the .05 level of significance. No significant correlation was found between the intercepts at the ordinate or, crucially, between the slopes of the best-fitting lines. Also, no correlation was found between the ERs in the two scanning tasks or with the ERs in the two working memory tasks.

Because the absence of significant correlations could indicate simply that our measures were not reliable, we checked the reliability of the RTs in both tasks by the split-half method. Significant correlations were obtained for the KBR task [$r(14) = .90$, $p < .01$] and the FP task [$r(14) = .91$, $p < .01$]. Thus, the lack of correlations between the RT measures does not indicate simply that these measures were so noisy as to be unreliable.

Discussion

The results from the two scanning tasks replicated those reported previously in the literature: Time to scan across visual mental images increased linearly with increases in the distance scanned. However, although it has long been assumed that the image-scanning processes involved in the two paradigms are identical, the results challenge this view. In fact, the speed of the scanning processes was not the same in the two tasks. The participants scanned the same distances more slowly in the KBR task than they did in the FP task. Furthermore, the participants who scanned relatively quickly in one task did not necessarily do so in the other. Indeed, the processes involved in the two scanning tasks did not have the same average speed, nor were these processes initiated equally quickly (as reflected in the intercept). These findings suggest that the processes involved in image scanning may be more complex than they initially appeared.

The fact that there was no correlation between the errors in the two scanning tasks should be interpreted cautiously. The ERs in the KBR task were so low that this measure may not be sensitive enough, with the result that it is not correlated with any other measure. Moreover, we found no correlation between performance in the two working memory tasks and any of the measures collected in the two image-scanning tasks. However, we again must interpret this finding with caution; the number of experimental trials may not have been large enough to provide a sensitive measure of the efficiency of the VWM and SWM tasks.

Thus far, we have a strong suggestion that scanning visual mental images is more complex than simply shifting attention over an imaged object. The following experiment was an attempt to clarify the nature of the processes involved in the two scanning tasks. In addition, because we had to be cautious in accepting the few correlations found in Experiment 1, a replication was needed.

EXPERIMENT 2

Why did we not find a clear relationship between the ease of scanning in the two tasks? In this experiment, we considered two hypotheses that might explain this lack of relationship. Our first hypothesis was that the processes recruited in the two tasks were essentially different. Specifically, we considered that in the KBR task, the participants drew primarily on transformational processes to scan, whereas in the FP task, they used attentional processes. In the latter task, when the participants determined whether or not an arrow pointed to the location of a previously seen dot, most of them reported mentally "projecting" the line of the arrow and checking whether it reached one of the targets. In the KBR task, where the participants shifted a small spot between two points, they might have been relying on a transformation process. The instructions required the participants first to focus mentally on the departure point (i.e., the dot that had the color named first) before mentally scanning to the arrival point (the dot that had the color named second).

In order to investigate this hypothesis, we added two new tasks to those used in the previous experiment—namely, a visual search task (Treisman & Gelade, 1980) and a mental rotation task (Cooper & Shepard, 1973). These tasks were selected because they involve processes that are also used in one or the other scanning strategies. In the visual search task, participants must determine whether or not a letter with a specific color (i.e., the target) is present in a pattern that includes the same letters with different colors and different letters with the same color (distractors). This task involves shifting attention over the pattern, which is supported by the classic finding of a linear relationship between the number of distractors and RT (Treisman & Gelade, 1980). In the mental rotation task, participants decide whether a letter is presented in its normal version or as a mirror image, regardless of its orientation in the picture plane. The classic finding is that RT increases with increases in the angular departure of the letter from the standard upright orientation, which suggests that the image is mentally rotated (Cooper & Shepard, 1973).

We reasoned that if an attentional process lies at the heart of scanning in the FP task, the slopes of the best-fitting lines in this task should be correlated with those in the visual search task, but not with those in the mental rotation task. Conversely, if a transformation process lies at the heart of the KBR task, we should find a correlation between the slopes of the best-fitting lines and those in the mental rotation task, but not with those in the visual search task. These predictions rely, however, on the assumption that the translation transformation used in scanning relies on at least some of the same processes as those used in the rotation transformation.

The second hypothesis we considered in this experiment is that the slope of the best-fitting line in the FP scanning task reflects not only an image-scanning process, but also the process of discriminating between the target and the distractors. To investigate this hypothesis, we designed an additional task; in this task, we replicated the FP procedure, except that we deleted the *no* trials, in which arrows were not pointing at the location of a previously seen dot. On each trial in this task, the participants were asked to extend mentally the arrow and to press a button when reaching one of the dots. In this new task, which we will refer to as the *FP reduced* task, the slope of the best-fitting line should reflect only image scanning, not the discrimination process. We assumed that if the slopes of the best-fitting lines are not affected by the discriminative process in the FP task, we should observe a correlation between these slopes and those in the FP reduced task.

Method

Participants

Sixteen undergraduates from the Institute of Psychology of René Descartes University, who had not participated in the previous experiment, participated as unpaid volunteers in this experiment. Their average age was 26 years 8 months. Fourteen were right-handed, and 2 were left-handed. Those who reported having followed the instructions less than 75% of the time were excluded from the sample; 1 participant had to be replaced for this reason.

Materials and Procedure

The participants were informed that the experiment would investigate visual perception and visual memory. They were tested individually with the same materials and the same postexperiment briefing as those in Experiment 1.

Scanning tasks. We administered three scanning tasks in this experiment. The stimulus configurations used in Experiment 1 were also used here.

The KBR and the FP tasks. We replicated the two scanning tasks in Experiment 1.

The FP reduced task. On each trial, the participants saw a pattern of five colored dots for 4 sec on a computer screen. This pattern was replaced by a blank field for 2 sec in order to eliminate any residual iconic image. Then an arrow appeared until the participant responded. In a learning phase similar to that in the KBR task, the participants were asked to form a mental image of the pattern of dots and compare their image with the drawing. When they thought that their image was accurate, they were allowed to continue the task. The stimuli were the same as those used in the FP task. In the test phase, the participants were told that on every trial, an arrow would point to one of the five colored dots. When the participants saw the arrow, they were to mentally shift a small spot from the tip of the arrow until it reached the colored dot at which the arrow pointed. As soon as it reached the target, they were to press a button. The participants received 40 trials in a single block. Trials were presented randomly, except that no more than 2 trials with the same target dots could occur in a row. The presentation of the arrow started a clock, which was stopped when the participants pressed the button; RTs were recorded.

Working memory tasks. The materials and the procedure for the working memory tasks were the same as those in Experiment 1.

Visual search task. For the visual search task, we constructed four displays consisting of 1, 5, 15, or 30 items, respectively. Each display subtended 14º × 8º, and each letter subtended 0.8º × 0.6º. The distractors were randomly distributed in each display. We divided each display into eight sections to ensure that the targets did not tend to cluster in one region. For each display size, we created eight patterns, one with a target randomly placed in each section. We also created, for each display size, eight patterns that did not contain a target. The target was a green uppercase letter T. The distractors were brown uppercase Ts and green uppercase Xs, with the two kinds of distractors appearing roughly equally often in each stimulus.

At the beginning of each trial, a fixation cross was displayed for 1 sec. This fixation point was then replaced by one of the stimulus patterns. The participants were instructed to press a button with their dominant hand if they detected a target and to press the other button with the other hand if they could not find a target. They were told to respond as quickly and accurately as possible. The presentation of a pattern started a clock that was stopped when the participants pressed either button; the response and RT were recorded. Trials on which the participants made an error were repeated at the end of the block. Four practice trials were presented prior to the test trials. The participants received the set of 64 trials (4 displays × 8 patterns × 2 response types) in one block in a random order, and the set was presented again in a second block (with a 10-sec pause between the two blocks).

Mental rotation task. The test stimulus was an asymmetric uppercase letter (F). This letter could be presented in either its normal version or its mirror version. Each type of stimulus was displayed in nine equally spaced orientations by steps of 40º.

At the beginning of each trial, a fixation point was displayed for 1 sec at the center of the computer screen. This fixation point was replaced by the letter F in one of its possible orientations in the picture plane. The participants' task was to decide whether the letter was presented in its normal or mirror image version. They pressed the button under their dominant hand for a normal version and the button under their other hand for the mirror version. The letter was displayed until the participants pressed one of the two buttons. If the participants made an error, the trial was repeated at the end of the block of trials. The participants were told to respond as quickly and accurately as possible. The presentation of the test stimulus started a clock, which was stopped when either button was pressed; the response and RT were recorded.

Before the experimental phase, the participants performed 4 practice trials, 2 with the normal version and 2 with the mirror version. The computer provided feedback regarding errors. A block of 90 randomized experimental trials was presented to the participants, with a 10-sec pause between the two halves of the session. Each of the nine orientations was presented five times in its normal version and five times in its mirror version. Although only one letter was used, the participants did report afterward that they had used a mental rotation strategy, and the data support these reports.

General procedure. Each participant completed the seven tasks included in this experiment. The order of the KBR task and the FP task was counterbalanced over participants, as was the order of the two working memory tasks that separated them. After completing these four tasks, the participants performed the three additional tasks. They started with the FP reduced task. Then they performed the visual search and the mental rotation tasks. The order of the latter two tasks was counterbalanced over participants. The patterns used in the three scanning tasks were also counterbalanced across participants.

Results

As in Experiment 1, the first step was to check that the earlier findings were replicated. We also examined the slopes of the best-fitting lines and intercept values. Then we considered more precisely the relationships between the processes involved in the tasks by conducting correlational analyses.

Preliminary analyses did not reveal any effect of the participants' gender, of the order of tasks, or of the patterns used on the ER and RT measures. Thus, we pooled over these factors and will not mention them further in the following report of results.

Scanning Tasks

ERs. The average ER was 1.8% in the KBR task and 14.8% in the FP task. Because all of the items in the FP reduced task were *yes* items, there was no measure of error.

RTs. As in Experiment 1, we considered only RTs from *yes* trials. We also replaced the outliers by the same method as that described earlier. Outliers occurred in 1.7% of the trials in the KBR task, 2.3% in the FP task, and 1.9% in the FP reduced task. In the KBR task, as was expected, RTs varied for the different distances [$F(9,135) = 10.57$, $p < .0005$] and increased linearly with increasing distance [$F(1,15) = 18.09$, $p < .001$]. We averaged the RTs over the 16 participants for each distance and calculated the best-fitting line on these data. We found that RTs and distances were highly correlated [$r(8) = .95$, $p < .01$; see Figure 3].

In the FP task, as in Experiment 1, the participants required more time when the distance between the tip of the arrow and the target dot was longer. This effect of distance on RTs was significant [$F(9,135) = 17.80$, $p < .0005$], with a strong linear component [$F(1,15) = 49.08$, $p < .0005$]. We averaged the RTs over the 16 participants for each distance and calculated the best-fitting line on these

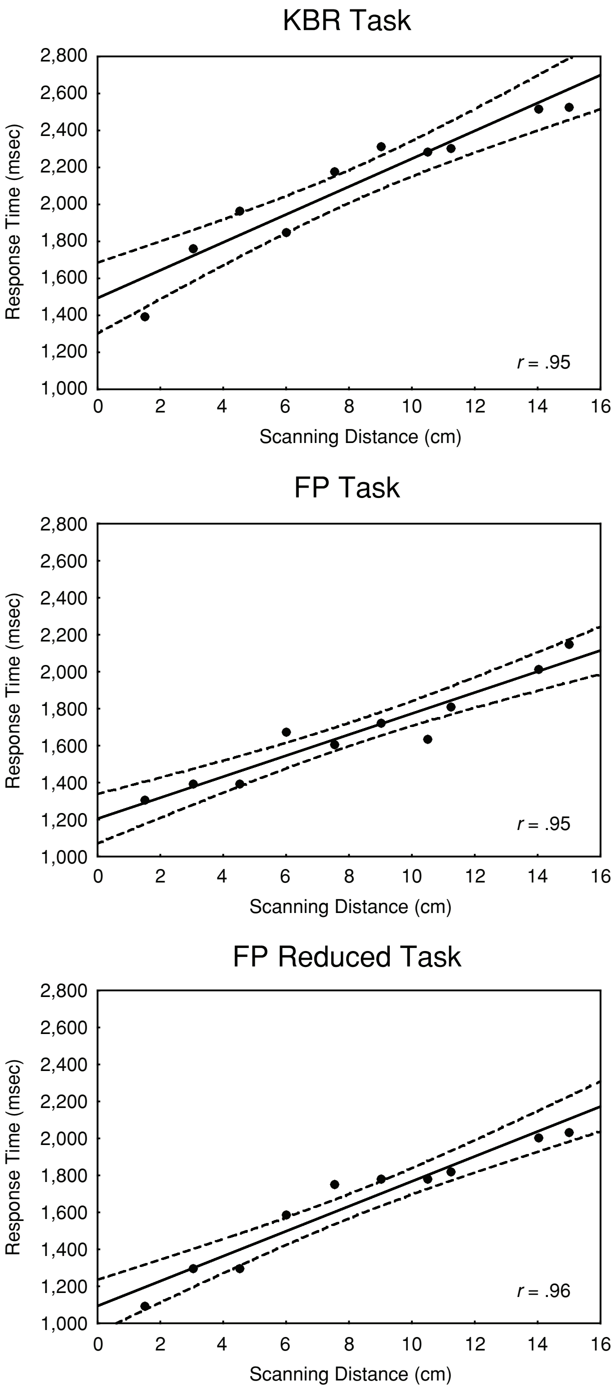

Figure 3. Experiment 2: Time to scan increasing distances in the image-scanning tasks.

data. We found that RTs and distances were highly correlated [$r(8) = .95$, $p < .01$; see Figure 3].

In the FP reduced task, distance affected RTs [$F(9,135) = 13.24$, $p < .0005$]. As is evident in Figure 3, there was a strong linear component [$F(1,15) = 21.58$, $p < .0005$]. By averaging the RTs of the participants for each distance and calculating the best-fitting line on mean times, we found that RTs and distances were highly correlated [$r(8) = .96$, $p < .01$]. This finding provides good evidence that the participants preserved the appropriate interdot distances in their images.

We calculated the slopes of the best-fitting lines over the 16 participants. Although the mean slope for the KBR task ($M = 76$ msec/cm) at first appeared steeper than the one for the FP task ($M = 52$ msec/cm) and the FP reduced task ($M = 68$ msec/cm), these differences were not significant. However, the participants required different amounts of time in the three tasks: KBR ($M =$ 2,122 msec), FP ($M = 1{,}686$ msec), and FP reduced ($M =$ 1,650 msec) [$F(2,30) = 5.00$, $p < .025$]. Paired comparisons indicated that mean RTs differed significantly only between the KBR and the FP tasks [$F(1,15) = 4.84$, $p <$ .05] and the KBR and the FP reduced tasks [$F(1,15) =$ 11.72, $p < .005$]. The intercepts of the best-fitting lines also differed [$M = 1{,}499$ msec for the KBR task, $M =$ 1,257 msec for the FP task, and $M = 1{,}094$ msec for the FP reduced task; $F(2,30) = 5.24$, $p < .01$].

Working Memory Tasks

As in Experiment 1, only ERs were analyzed for these two tasks as measures of the efficiency of working memory. The participants made more errors in the SWM task than in the VWM task [16.0% vs. 5.0%, respectively; $F(1,15) = 53.98$, $p < .0005$]. The SWM task thus was more difficult than the VWM task, as was already established in Experiment 1.

Visual Search Task

For each participant, we averaged ERs and RTs for each of the four types of stimulus displays (1, 5, 15, or 30 letters presented), depending on whether or not the target (green T) was present. We calculated the mean ERs and RTs for each type of pattern for each participant, regardless of the presence of the target.

ERs. Errors occurred in 3.5% of all the trials. We sorted the errors into false alarms and omissions. An ANOVA revealed that the frequency of errors did not differ for the two classes.

RTs. We performed three ANOVAs on the data. The participants required different amounts of time for the different-sized displays when the target was present [$F(3,45) = 100.94$, $p < .0005$], when it was not present [$F(3,45) = 56.73$, $p < .0005$], and when all of the trials were considered together [$F(3,45) = 41.83$, $p < .0005$]. In short, RTs increased with increasing numbers of distractors. We calculated the best-fitting line from mean RTs for each type of pattern over the 16 participants only for the *yes* trials and found that RTs increased linearly as the number of distractors increased [$F(1,15) = 43.18$, $p < .0005$]. The correlation coefficient between RTs and the number of distractors was $r(2) = .99$, $p < .05$. These results replicated those reported in earlier studies; the participants apparently followed the instructions, which legitimates the use of these data for the subsequent correlational analysis.

Mental Rotation Task

We averaged RTs over participants for each of the nine possible angles (from 0º to 320º), regardless of the presented version of the letter (normal or mirror).

ERs. The participants made errors on 2.3% of the test trials.

RTs. As was expected, the RTs differed for the different angles, from 0º to 180º [$F(4,60) = 133.08, p < .0001$]. We calculated the best-fitting line from the mean RTs for each angle over the 16 participants and found that RTs increased linearly with greater angular disparity from vertical [$F(1,15) = 232.09, p < .0001$]. The correlation coefficient between RTs and angular disparity was $r(3) = .98, p < .05$. These findings replicated the original findings by Cooper and Shepard (1973) and confirmed that the participants used mental rotation; thus, we were justified in including these data in the subsequent correlational analyses.

Correlational Analyses

We performed correlations in the same way as in the previous experiment, with a larger number of individual measures. For the three scanning tasks, the visual search task, and the mental rotation task, we used three values for each participant: (1) the correlation coefficient between times and the relevant independent variable (distances for the scanning tasks, number of distractors for the visual search task, and angle of rotation for the mental rotation task), (2) the slope of the best-fitting line, and (3) the intercept at the ordinate. In addition, ERs were available for the first two scanning tasks, the visual search task, the mental rotation task, and the two working memory tasks (see Appendix B).

We first examined the two scanning tasks from the previous experiment and did not find any sign of a systematic relationship between the KBR and the FP tasks, for any of the three RT measures (time/distance correlation coefficient, intercept, and slope). None of the three correlation coefficients reached or even approached significance. Similarly, we failed to find correlations between the same measures for the FP and the FP reduced tasks. However, we did find correlations between the KBR and the FP reduced task slopes of the best-fitting lines [$r(14) = .81$, $p < .01$], as well as the intercepts [$r(14) = .56, p < .05$]. Although the systematicity of the relationship between time and distance (as indicated by the magnitude of the r value) was not related in the two tasks, the speed of scanning per se clearly was related, suggesting that these tasks drew on at least some common underlying processes.

Performance in the working memory tasks did not correlate with any aspect of the participants' performance in the other tasks. However, we did find a positive correlation between the ERs in the two working memory tasks [$r(14) = .62, p < .02$], a finding compatible with the hypothesis that the two tasks share common processes.

As was expected, the measures of the slope for the *yes* trials in the visual search task were, in fact, correlated with the measures of the slope for the FP task [$r(14) = .51, p < .05$]. In addition, the intercept in visual search was strongly correlated with the intercept in the FP task [$r(14) = .83, p < .01$]. But contrary to our predictions, we found no sign that the measures for the mental rotation task correlated with those for the KBR task.

As in Experiment 1, we examined the reliability of the RTs in the experimental tasks by the split-half method. We found significant correlations for the KBR task [$r(14) = .97$], the FP task [$r(14) = .92$], the FP reduced task [$r(14) = .84$], the visual search task [$r(14) = .97$], and the mental rotation task [$r(14) = .94$; all ps $< .01$]. These values attest that the low number of significant correlations among the variables was not a result of our measures being unreliable.

Discussion

We again failed to find a relationship between the measures of image scanning in the two scanning paradigms. We, of course, must be cautious in affirming a null finding, but this result, in conjunction with that in Experiment 1, supports the hypothesis that there are two distinct scanning processes. In addition, we failed to find a relationship between performance in the FP task and the FP reduced task, but we did find a correlation between the slopes and intercepts for the KBR and FP reduced tasks. This last finding is important for two reasons. First, it shows that our data are not simply so noisy that nothing is correlated with them. Second, it indicates that a common process was drawn upon in the KBR and the FP reduced tasks. If the same process were also used in the FP task, we should have found comparable correlations there.

However, there is an alternative interpretation for the lack of correlation between the KBR and FP reduced tasks and the FP task: Perhaps RT in the FP task reflects not only the scanning process, but also the additional cost of discriminating the target point from the distractors. If this additional requirement affects the slope of the best-fitting line, this could explain why, when the discrimination is easy, the pattern of results is similar to the one in the KBR task. The close relationship between the processes involved in the KBR task and those in the FP task when it is limited to scanning is compatible with the hypothesis that the same scanning process is used in all the tasks. If so, the difference in slopes in the KBR and FP tasks would reflect the effects of discriminating target and distractors in the FP task: People may scan more slowly when the discrimination is more difficult, and if people differ in how difficult the discrimination seems (or in how careful they are), the scanning times will vary. If so, we would not find correlations between the KBR and the FP tasks, even though the same scanning process was, in fact, at work. Indeed, we found that slopes in the visual search task were correlated with those in the FP task. This finding is as expected if attention processes—specifically, those involved in discrimination—play a key role in the FP task.

In short, the difficulty of discriminating the target point from distractors, which in turn would modulate scanning speed, could explain the lack of relationship between measures of scanning speed in the KBR and FP tasks. We note, however, that this factor could not explain why scanning in the FP task was actually faster than that in the KBR task. However, the absolute values of the slopes are not important, because other factors may contribute to them: For example, in the KBR task, the participants did not know exactly where to scan to find the target object, which may have added additional time to the slope if they required progressively more time to decide where to scan when longer distances were involved. This estimation process need not be related to scanning times per se. For present purposes, the crucial comparisons are over individuals: If the same scanning process is used in the different tasks, we should find that the slopes are correlated—but not necessarily the same, if other processes also contribute to them. The following experiment was an attempt to study the possible role of the discrimination process in the FP task in producing the present findings.

EXPERIMENT 3

We argued in the previous experiment that knowing where to scan could affect the slopes for the KBR task. If so, not only would the slopes be steeper, but the intercept would also be greater. We did, in fact, obtain these results. Moreover, we suggested that when the discrimination is difficult, participants may slow down their scanning, which may obscure the contribution of the scanning process itself. To study the importance of the precision of the direction cue and the difficulty of discriminating the targets, we varied the difficulty of the discrimination between targets and distractor points in the FP task. Starting from the subtle discriminations (and hence, high level of difficulty) incorporated in Experiment 1, we added two progressively easier levels of discriminability (and hence, lower levels of difficulty). For each of the three resulting levels of discriminability (high, medium, and low), the participants performed exactly the same task; that is, they decided whether or not an arrow pointed at the location occupied by one of the previously seen dots. The difference between the three levels was the angle with which the arrow missed any of the dots; the discriminability increased as this angle increased.

A second problem we considered in this experiment was the relatively low sensitivity of our measures of working memory capacity, due to a relatively small number of experimental trials. To allow us better to investigate the working memory processes involved in the scanning tasks, we created more trials in the two working memory tasks. Thus, we could be more confident in the measure of the efficiency of the VWM and SWM performance.

Method

Participants

Sixteen undergraduates from the Institute of Psychology of René Descartes University, who had not taken part in any of the previous experiments, participated as paid volunteers. The average age of the participants was 19 years 8 months. Fifteen participants were right-handed, and 1 was left-handed. One participant had to be replaced because he reported that he had not followed the instructions at least 75% of the time.

Materials and Procedure

The participants were tested individually and were informed only that this experiment would concern visual perception and visual memory. They were asked to fill in a postexperimental questionnaire after completing the experimental tasks. None of the participants reported having suspected a relationship between time and distance. The participants started with one of the two image-scanning tasks. The order of the two tasks was counterbalanced over participants. The two working memory tasks were completed between the two scanning tasks.

Scanning tasks. The participants performed image scanning with the same two patterns of five colored dots as those used in the previous experiments.

The KBR task. The materials and procedure were exactly the same as those in the KBR task in the first two experiments.

The FP task. We used exactly the same task and procedure as before, except that we introduced three levels of discriminability for the *no* trials, in which the arrow did not point at a location previously occupied by one of the dots. The presentation sequence on each trial was identical to the one in the FP task in Experiments 1 and 2. For each level of discriminability, the participants were instructed to decide as quickly and accurately as possible, for each trial, whether the arrow pointed at a location of one of the previously seen dots. For the high level of discriminability, the arrow in *no* trials missed all the dots by more than 65º; for the medium level, by 45º; for the low level, by 40º or less. Two blocks of 40 experimental trials were completed by the participants for each level of difficulty. The order of the three conditions was counterbalanced over participants. The presentation of the pattern was counterbalanced over the three conditions for each participant, with separate practice trials for each level of difficulty (allowing the participant to calibrate the level of discrimination required).

Working memory tasks. The materials and the procedure used in the VWM and SWM tasks were identical to those in Experiment 2. However, in this experiment, the participants performed six experimental blocks, instead of two, in each working memory task. The six blocks of trials were presented in a random order, with one block of practice trials before the test trials. The blocks were separated by a 10-sec pause. The order of the two tasks was counterbalanced over participants.

Results

As in the previous experiments, the first step consisted of verifying that the data replicated the classic results reported in image-scanning experiments. Following this, we investigated the relationships among the RTs collected from each participant. Prior analyses revealed that there was no effect of gender or of order of the tasks, and thus we pooled over those factors and will not mention them further.

Scanning Tasks

ERs. The participants made errors on 1.3% of the trials in the KBR task; they made errors in the FP task on 8.4%, 12.3%, and 13.5% for the high, medium, and low levels of discriminability, respectively. An ANOVA revealed that the effect of level of discriminability was significant [$F(2,30) = 11.28$, $p < .0005$]; this finding validates our manipulation.

RTs. Only the times for the correct responses to *yes* trials were analyzed. Outliers were eliminated prior to analyses, using the same procedure as that described earlier. Outliers occurred in 2.0% of the trials in the KBR task. In the FP task, outliers occurred in 1.5% of the trials for the high level of discriminability, 1.8% for the medium level, and 2.1% for the low level. In the KBR task, RTs varied for the different distances [$F(9,135) = 21.20$, $p < .0005$] and increased with increasing distances [$F(1,15) = 35.32$, $p < .0005$]. We averaged the RTs over the 16 participants for each of the 10 distances. On the basis of these data, we calculated the best-fitting line. We found that RT and distance were highly correlated [$r(8) = .95$, $p < .01$; see Figure 4].

For the FP task, the ANOVA revealed that the effect of distance on RT was significant for the high level of discriminability trials [$F(9,135) = 6.80$], for the medium-level trials [$F(9,135) = 14.78$], and for the low-level trials [$F(9,135) = 16.54$; all ps $< .0005$]. For every level of discriminability, RTs increased with increasing distance [$F(1,15) = 28.46$, $F(1,15) = 71.31$, and $F(1,15) = 24.74$, respectively; all ps $< .0005$]. A single analysis that included both distance and level of discriminability revealed that the variables did, in fact, interact [$F(18,405) = 1.76$, $p < .05$]. We averaged the RTs over the 16 participants for each distance and calculated the best-fitting functions for these data. The RTs were correlated with increasing distance for the high level of discriminability [$r(8) = .92$, $p < .01$], the medium level [$r(8) = .95$, $p < .01$], and the low level [$r(8) = .91$, $p < .01$; see Figure 5].

To examine the bases for the observed interaction between distance and difficulty, we analyzed the slopes of the best-fitting lines in the KBR task and in each of the three levels of discriminability of the FP task. The four slopes varied [$F(3,45) = 7.99$, $p < .0005$]. The mean slope of the best-fitting line was steeper for the KBR task (M = 88 msec/cm) than for the FP task for the high level of discriminability [M = 31 msec/cm; $F(1,15) = 16.51$, $p < .005$], the medium level [M = 37 msec/cm; $F(1,15) = 9.81$, $p < .005$], and the low level [M = 48 msec/cm; $F(1,15) = 4.69$, $p < .025$]. The slopes of the best-fitting lines in the three conditions of discriminability in the FP task did not differ significantly from each other [$F(2,30) = 2.45$, $p = .10$]. However, the effect of discriminability on the linear component of the slopes, with more difficult discriminations leading to steeper slopes, was significant [$F(1,15) = 4.92$, $p < .05$].

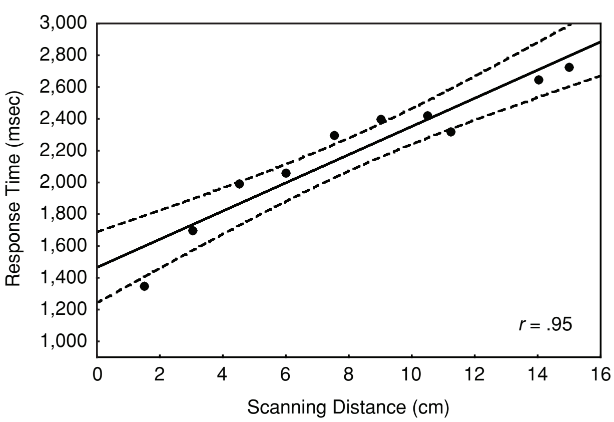

Figure 4. Experiment 3: Time to scan increasing distances in the Kosslyn, Ball, and Reiser (1978) task.

In addition, the average RTs differed significantly among the four scanning tasks [$F(3,45) = 17.99$, $p < .0005$]. Overall scanning times were longer in the KBR task (M = 2,219 msec) than in the FP task for the high level of discriminability [M = 1,292 msec; $F(1,15) = 25.50$, $p < .0005$], the medium level [M = 1,357 msec; $F(1,15) = 16.10$, $p < .005$], and the low level [M = 1,309 msec; $F(1,15) = 21.43$, $p < .0005$]. The average intercept value was 1,499 msec for the KBR task. For the FP task, the average values were 1,041 msec for the high level of discriminability, 1,052 msec for the medium level, and 910 msec for the low level. All three values were significantly shorter than the value for the KBR task [$F(1,15) = 19.48$, $p < .001$, $F(1,15) = 17.21$, $p < .001$, and $F(1,15) = 31.97$, $p < .0005$, respectively]. For the FP task, there was no difference among the intercepts for the three levels of discriminability.

Working Memory Tasks

Errors occurred significantly more often in the SWM task (15.3%) than in the VWM task (4.4%) [$F(1,15) = 24.87$, $p < .0005$].

Correlational Analyses

We computed correlations based on individual data. For the KBR task and the three levels of discriminability in the FP task, the three chronometric measures were the same as those in Experiment 2. ERs were also considered for the scanning tasks and the two working memory tasks (see Appendix C).

The slopes of the best-fitting lines for the KBR task and the FP task were not correlated for the high, medium, or low level of discriminability [$r(14) = .47$, $r(14) = .02$, and $r(14) = .03$, respectively]. No other correlation coefficients were significant. In particular, no relationship appeared between the time/distance correlations for the KBR task and any version of the FP task. The ERs in the two working memory tasks did not correlate with each other or with the scanning results.

Following the procedure used in the two previous experiments, we checked the reliability of the RTs in the experimental tasks by the split-half method. Significant correlations were obtained for the KBR task [$r(14) = .96$] and for high, medium, and low levels of discriminability in the FP task [$r(14) = .95$, $r(14) = .88$, and $r(14) = .84$, respectively; all ps $< .01$]. These values show that noisy measurements cannot explain the low number of correlation coefficients.

Discussion

The results for the KBR task replicated the typical results, with a low ER and a strong linear relationship between RTs and distances. Furthermore, for each level of

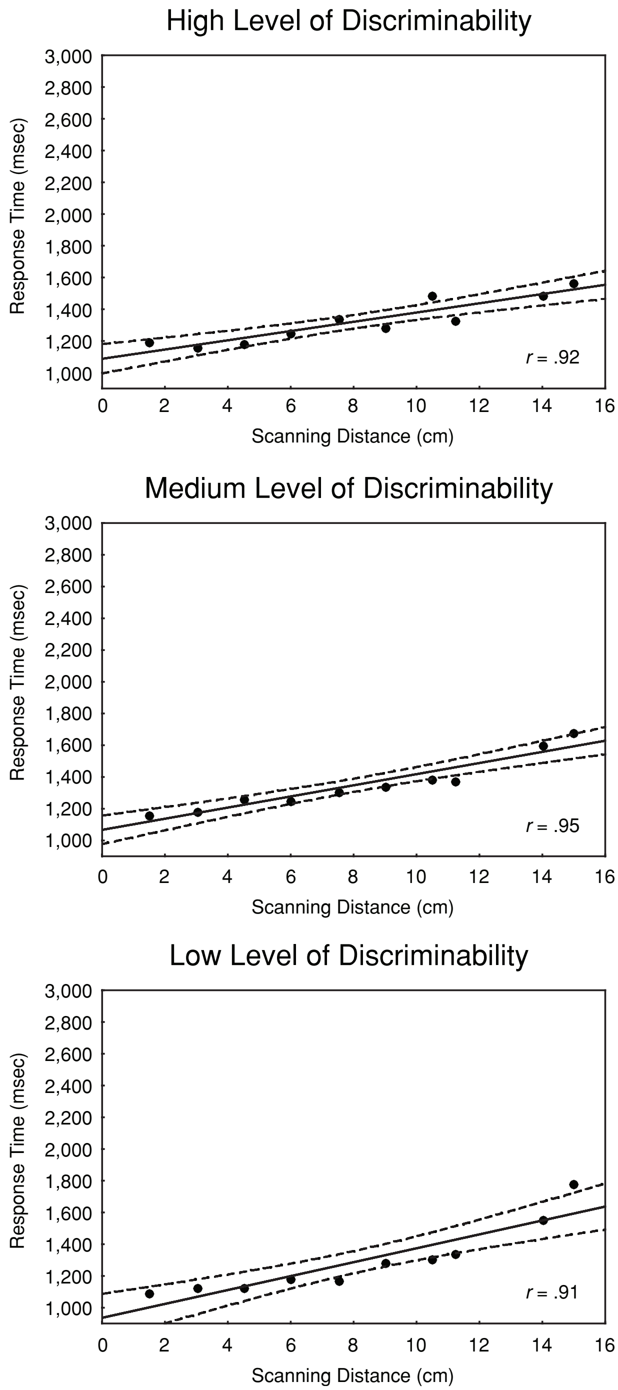

Figure 5. Experiment 3: Time to scan increasing distances in the Finke and Pinker (1982) task for each level of discriminability.

discriminability in the FP task, we replicated the standard increase in times with increases in distance. This is not surprising for the low level of discriminability (which was the level used in the original Finke and Pinker [1982] experiment), but new information is provided by the finding that the time/distance correlation was also obtained for the two higher levels of discriminability. Thus, regardless of the difficulty of the task, the participants seemed to form a mental image of the pattern and mentally scan the distance between the tip of the arrow and the target dot, even though they were not explicitly instructed to do so. On average, the participants scanned more quickly in the FP task than in the KBR task, regardless of the level of discriminability. The slopes steadily increased as the level of discriminability decreased. But more important than that, in no case was there a correlation between these slopes and the KBR slopes. Thus, although the speed of the scanning processes depended on the difficulty of discriminating between target and distractor dots, this additional process did not appear to be masking the contribution of the scanning process per se. Even when the discrimination was trivially easy, we still did not find a correlation between the slope of scanning in the two tasks.

The results thus invite the inference that there are two different image-scanning processes involved in the two scanning paradigms. The lack of correlation between the chronometric measures of scanning in the two scanning tasks is unlikely to be a consequence of the discrimination process in the FP paradigm. Even by eliminating the effect of the processes involved in discrimination (the *perceptual crowding* effects), there is still no relationship between the scanning processes in the two paradigms.

Lastly, by adding blocks of trials in the two working memory tasks, we attempted to evaluate more precisely the efficiency of VWM and SWM tasks. However, there still was no evidence that image-scanning processes, in either paradigm, require spatial working memory resources.

GENERAL DISCUSSION

The results of the present experiments converge in demonstrating that different image-scanning processes are evoked by two classic paradigms: the one designed by Kosslyn et al. (1978) and the other by Finke and Pinker (1982). Some features, however, are common to the two paradigms. Importantly, more time is required to scan greater distances in both tasks, and both paradigms consequently support the theoretical conception of visual mental images as depictive representations.

However, the amount of additional time to scan additional amounts of distance (as reflected by the slopes of the best-fitting lines) is larger in the KBR than in the FP paradigm. A possible account of this result is that in the KBR paradigm, the participants were instructed to visualize a spot, whereas in the FP tasks, the scanning did not involve a spot. It is thus theoretically possible that differences between the KBR and the FP tasks did not involve any difference in scanning per se or different scan mechanisms but, simply, the extra demands required by the fact of imaging a spot. In addition, whereas the KBR task requires participants to encode both location and identity information, the FP task requires only the former. Moreover, as was noted earlier, the KBR task may have involved greater directional uncertainty, which resulted in longer *set up times* before scanning began with longer distances. Lastly, the KBR task had both visual and auditory components, whereas the FP task was only visual. These considerations suggest that the KBR task may have involved additional processes not engaged by the FP task, which is consistent with the observation that RTs on the KBR task were longer than those on the FP task.

Nevertheless, if the same scanning process were embedded in the two tasks, we should have found correlations in slopes over participants. The other factors would affect the absolute values of the slopes, but these effects should have been added onto those of a hypothetical common scanning process—and thus, the relative speed of scanning per se should have been evident when the two paradigms were compared. The observed differences in RT slopes are evidence that different processes underlie image scanning in the two paradigms. Indeed, there were no systematic correlations between the chronometric measures in the two paradigms, confirming that people do not use a single, unitary scanning process to perform the two sorts of tasks. We did not find any correlation that reached significance between the slopes of the best-fitting lines in the two scanning paradigms, which is the crucial statistical index for tracking image-scanning processes.

To conclude, we argue that two image-scanning processes should be distinguished, instead of assuming that there is a single one purportedly drawn upon in both Kosslyn et al.'s (1978) and Finke and Pinker's (1982) tasks. The dissociation between the two scanning processes would be even more strongly documented if distinct neural pathways were shown to be activated in the two scanning paradigms.

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APPENDIX A
Correlation Matrix for Experiment 1

		Correlation Coefficient Between Times and Distances		Slope of the Best-Fitting Line		Intercept at the Ordinate		Error Rate			
	Task	KBR	FP	KBR	FP	KBR	FP	KBR	FP	VWM	SWM
Correlation coefficient between times and distances	KBR	1.00	.52*	.63*	.19	−.35	−.71*	.00	.00	.32	.11
	FP		1.00	.25	.60*	−.40	−.48	.06	.38	.30	.13
Slope of the best-fitting line	KBR			1.00	.46	.29	−.21	−.12	.18	.44	−.08
	FP				1.00	−.03	.00	.03	.38	.30	−.23
Intercept at the ordinate	KBR					1.00	.39	−.12	.14	.15	−.20
	FP						1.00	−.07	−.20	−.11	−.31
Error rate	KBR							1.00	−.06	−.43	.43
	FP								1.00	.04	.25
	VWM									1.00	−.12
	SWM										1.00

Note—KBR, the Kosslyn, Ball, and Reiser (1978) task; FP, the Finke and Pinker (1982) task; VWM, the verbal working memory task; SWM, the spatial working memory task. *$p < .05$ or less.

APPENDIX B
Correlation Matrix for Experiment 2

		Correlation Coefficient Between Times and the Relevant Independent Variable**					Slope of the Best-Fitting Line					Intercept at the Ordinate					Error Rate					
	Task	KBR	FP	FPR	VS	MR	KBR	FP	FPR	VS	MR	KBR	FP	FPR	VS	MR	KBR	FP	VWM	SWM	VS	MR
Correlation coefficient between times and the relevant independent variable**	KBR	1.00	.16	.47	.11	.14	.66*	−.21	.51*	−.29	−.02	−.54*	−.20	−.04	−.35	.02	.33	−.03	−.13	−.23	.20	.50*
	FP		1.00	.08	.45	.42	.14	.81*	.14	.25	−.08	−.18	−.23	−.10	−.05	.47	.08	.05	.10	−.15	.10	.47
	FPR			1.00	.33	.18	.43	−.21	.48	−.17	.31	−.40	−.44	−.55*	−.40	−.01	.50*	−.01	−.21	−.42	−.03	.08
	VS				1.00	.57*	.09	.42	.16	.21	−.03	−.24	−.34	−.31	−.45	.10	.11	.15	.18	−.22	−.48	.08
	MR					1.00	.12	.45	.05	.22	.22	−.18	−.54*	−.36	−.50*	.01	−.08	.10	.12	−.23	−.15	.24
Slope of the best-fitting line	KBR						1.00	.05	.81*	.01	.23	−.12	.01	.01	−.08	.27	.49	−.37	−.08	−.08	−.11	.32
	FP							1.00	.08	.51*	−.06	.06	−.01	−.04	.14	.48	.02	−.10	.09	−.05	−.18	.38
	FPR								1.00	.00	.04	−.23	.16	−.14	−.01	.40	.34	−.16	−.30	−.04	−.39	.36
	VS									1.00	.38	.00	.34	−.27	.44	.60*	−.29	−.31	.28	.24	−.03	.25
	MR										1.00	.21	.06	−.24	.09	.08	.26	−.07	.35	.27	.23	−.07
Intercept at the ordinate	KBR											1.00	.30	.56*	.32	.14	.24	.28	.40	.28	−.06	−.60*
	FP												1.00	.33	.83*	.45	−.16	.07	.03	.45	.07	−.10
	FPR													1.00	.25	.08	.20	.13	.06	.18	.12	−.04
	VS														1.00	.57*	−.15	−.17	.10	.39	.30	−.09
	MR															1.00	−.04	.03	.07	.02	.03	.23
Error rate	KBR																1.00	−.06	.15	−.05	−.10	.02
	FP																	1.00	.04	−.15	.05	−.36
	VWM																		1.00	.62*	.04	−.25
	SWM																			1.00	−.03	.03
	VS																				1.00	.09
	MR																					1.00

Note—KBR, the Kosslyn, Ball, and Reiser (1978) task; FP, the Finke and Pinker (1982) task; FPR, the FP reduced task; VS, the visual search task; MR, the mental rotation task; VWM, the verbal working memory task; SWM, the spatial working memory task. *$p < .05$ or less. **Relevant independent variables: distances for the KBR, FP, and FPR tasks; number of distractors for the VS task; and angle of rotation for the MR task.

APPENDIX C
Correlation Matrix for Experiment 3

		Correlation Coefficient Between Times and Distances				Slope of the Best-Fitting Line				Intercept at the Ordinate				Error Rate					
	Task	KBR	FP High	FP Medium	FP Low	KBR	FP High	FP Medium	FP Low	KBR	FP high	FP Medium	FP Low	KBR	FP High	FP Medium	FP Low	VWM	SWM
Correlation coefficient between times and distances	KBR	1.00	.32	.08	.31	.63*	.52*	.25	.42	−.14	.33	−.32	−.32	−.18	−.03	−.22	−.22	−.30	−.25
	FP high		1.00	.45	.16	.35	.72*	.38	.35	−.02	.01	−.32	−.42	−.05	.15	.46	−.12	−.63*	−.15
	FP medium			1.00	.03	.14	.11	.72*	.07	.18	−.01	−.30	−.12	−.18	.25	.22	−.06	−.30	.28
	FP low				1.00	−.02	.16	.08	.63*	−.49	.21	.13	−.44	−.31	−.17	−.26	−.29	−.23	−.36
Slope of the best-fitting line	KBR					1.00	.47	.02	.03	.47	.31	−.35	.12	.51*	−.19	−.13	−.39	−.19	−.30
	FP high						1.00	.14	.60*	.08	.47	−.12	−.44	−.02	.08	.27	.04	−.50*	−.24
	FP medium							1.00	.37	−.05	−.06	−.17	−.48	−.43	−.05	.09	.00	−.57*	.28
	FP low								1.00	−.23	.50*	.29	−.82*	−.30	.01	−.01	.01	−.55*	−.14
Intercept at the ordinate	KBR									1.00	.23	.19	.32	.63*	.15	.18	.03	.00	.07
	FP high										1.00	.39	−.19	.19	.21	.24	.19	.11	.21
	FP medium											1.00	−.18	.09	.29	.36	.45	.06	.15
	FP low												1.00	.35	.06	−.14	.05	.67*	.10
Error rate	KBR													1.00	−.03	.06	−.27	.15	−.13
	FP high														1.00	.54*	.62*	−.02	.29
	FP medium															1.00	.45	−.13	.26
	FP low																1.00	−.06	.52*
	VWM																	1.00	.28
	SWM																		1.00

Note—KBR, the Kosslyn, Ball, and Reiser (1978) task; FP, the Finke and Pinker (1982) task, with high, medium, and low levels of discriminability; VWM, the verbal working memory task; SWM, the spatial working memory task. $^{*}p < .05$ or less.

(Manuscript received June 23, 2004;
revision accepted for publication April 18, 2005.)