

Role of Spatial Location in Integration of Pictorial Information Across Saccades

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Identification of a fixated object in a visual display is facilitated by integrating information from a preview of that object in the periphery with information extracted on the subsequent foveal fixation (Pollatsek, Rayner, & Collins, 1984). These experiments investigated the extent to which this integration is dependent on the spatial location of the information remaining constant. Two preview objects were presented in the periphery; one fixated that region and named a single target object that appeared in the same spatial location in which one of the two preview objects had been presented. Of primary interest was the facilitative effect when a preview object was identical to the target object as a function of whether they were in the same spatial location. The major finding was that although there was a small effect of switching, there was still a substantial preview benefit even when the location of the identical object switched. In addition, the switching effect did not interact with the level of identity between the preview and target. There was also a preview benefit in conditions in which there were no eye movements and the preview and target objects were at least 5° apart. Thus, the data indicate that the process of object identification is relatively insensitive to location information and that object information and location information are coded fairly independently.

In viewing normal static displays such as pictures or text, the eyes move in a rapid ballistic fashion about 3–5 times per second (Rayner, 1978a). Between these eye movements or *saccades*, during which no useful information is extracted, visual information is extracted during the periods of *fixations* when the eyes are more-or-less still. Thus, the brain receives a series of snapshots of the external world from the fixations that it integrates into a coherent stable visual representation. The question of how these snapshots are integrated is a fundamental question confronting visual perception.

Pollatsek, Rayner, and Collins (1984) examined the integration process in picture perception in a series of experiments. Their technique was to present a single line drawing of an object in extrafoveal vision (either 5° or 10° from fixation) and to have subjects move their eyes to fixate the object. The subjects named the object when it was fixated, and the time to name the picture was used as a measure of the time it took to identify the line drawing when it was fixated. In a control condition, a square that was in extrafoveal vision changed to the target object when it was fixated. Subjects named the object about 100–130 ms faster when they had an extrafoveal preview than when there was merely a square in the same location. This *preview benefit* indicated that useful information had been extracted from the first

fixation and that this information aided in naming the target object when it was fixated. That is, information was taken from the fixation when the object was seen extrafoveally and integrated with the information seen on the subsequent fixation when the object was seen foveally.

The focus of this article is the role of spatial location in this process of integration of information across two fixations; that is, does the integration process depend on the information being in the same spatial location on the two fixations? To help frame the issue, we consider two extreme models of the integration process. At one extreme, integration from fixation to fixation is a very low-level process in some retinalike representation. This type of representation, in which the visual world is represented spatiotopically in a two-dimensional image, has been termed alternatively an *integrative visual buffer* (Jonides, Irwin, & Yantis, 1982; McConkie & Rayner, 1976), a *retinoid* (Trehub, 1977), or a *stable feature frame* (Feldman, 1985). If integration across fixations were to occur in this type of representation, the integration would have to be point by point (or at least spatially localized feature by feature). (We should point out that not all the theorists mentioned have posited integration across fixations in this medium.) Clearly, such a process would require quite precise alignment of the information from the two fixations, because similar information is on different places on the retina on the two fixations. At the other extreme, the integration process is quite abstract; for example, there might be location-independent object detectors that accumulate evidence for the existence of an object somewhere on the retina. According to this view, evidence would accumulate for an object from the extrafoveal information on the first fixation, and then more evidence for the object would accumulate from the foveal information on the second fixation. With such an integration process, it is conceivable that the relative spatial location of the two images would be irrelevant to the integration process.

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There is to date no work that bears directly on the role of spatial location in integrating information across fixations when viewing pictures. However, a strict point-by-point integration model seems untenable. In a series of experiments, Pollatsek et al. (1984) varied the relation of the extrafoveal object to the foveal object in order to gain insight into the level of representation used in the integration process. Of crucial interest was how much preview benefit would be obtained when the previewed picture was similar but not identical to the fixated picture. First, changing the size of the picture by 10% had no effect on the preview benefit, indicating that the integration of information was not occurring in a point-by-point manner as in the integrative visual buffer models cited earlier. However, more information than the concept was carried over from the first fixation because there was greater facilitation when the preview picture was physically identical to the target picture than when it was merely the same concept (e.g., one line drawing of a dog changed into a line drawing of a different dog seen from a somewhat different angle). Thus, some sort of visual representation of the first picture remained. Pollatsek et al. suggested that the representation could have been visual features. However, another possibility is that a neighborhood of representations in some sort of lexicon for pictures is activated by the extrafoveal preview (Kroll & Potter, 1984) and this excitation more efficiently activates the representation of the fixated picture when the preview is physically identical to it than when it merely represents the same basic concept.

Another finding that indicated that physical codes were involved in this integration of information was that visually similar pictures produced facilitation, especially when they were far from fixation. In one of their experiments, Pollatsek et al. (1984) manipulated the visual and semantic similarity of the preview object to the target object. If the target was a baseball bat, for example, the preview could either be a ball (semantically similar), a carrot (visually similar), or a tomato (both visually and semantically dissimilar). There was significant facilitation when the preview was visually similar but none when the preview was semantically similar. In fact, inhibition was observed (in relation to the square) when the preview was visually dissimilar to the target. Other experiments of Pollatsek et al. indicated, however, that name codes from the extrafoveal picture also influenced naming time; when the two pictures had the same name (even if they had different concepts), there was a small facilitation effect, whereas when the two pictures had different names, there was inhibition in relation to the control condition (the square preview). Thus, in conditions such as the carrot preview and bat target, visual facilitation was observed in spite of this inhibitory effect.

It is important to note that the pattern of results observed in the Pollatsek et al. (1984) experiments were somewhat different from those observed when the stimuli were words (Balota & Rayner, 1983; Rayner, 1978b; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980). With words, there was no evidence that visual codes were involved in the integration process. First, changing the case of all the letters from one fixation to the next did not affect the size of the facilitation effect (McConkie & Zola, 1979; Rayner et al.,

1980). Second, significant facilitation occurred when the first two or three letters of the preview were contained in the target (e.g., *chest* was a preview for *chart*). These two findings indicated that abstract letters were the code that was mediating the integration (Rayner et al., 1980). In addition, similar facilitation effects occurred in a condition in which the same retinal events occurred as in the basic paradigm but in which the words were not in the same spatial location (Rayner et al., 1978). In this condition, subjects saw the preview word extrafoveally for 200 ms, maintained fixation, then saw the target word foveally. The preview benefit for words thus did not depend on whether the preview and target were in the same perceived spatial location.

In summary, the results for word stimuli indicate that integration of information from fixation to fixation is completely at an abstract level: Changing visual features (as in a case change) had no effect, and changing the spatial location also had no effect. In contrast, the results for pictures indicate that the level of representation in the integration process may be more visual. Thus one might expect the relative spatial location of the objects to be important in the integration process, if one assumes that a visual level of integration implies that the integration process is location sensitive, whereas a more abstract level would imply that the process is not location sensitive.

We hasten to point out, however, that the level of the integration process and the role of spatial location are logically independent; for example, there could be relatively abstract lexical representations or object files (Kahneman & Treisman, 1984) in which evidence accumulates across fixations but in which a change in spatial location would defeat the integration process. These files could be tagged spatially, so that only evidence in a specific spatial location is integrated. Conversely, there may be some relatively low level visual process of integration in which a preprocessor can quickly realign similar representations in differing spatial locations to allow integration of these visual representations to proceed.

We should also note that the role of spatial location in the integration of information across fixations is part of the general issue of the relation of location information to object information, or of how *where* relates to *what*. A large body of research, both anatomical and behavioral, has accumulated that suggests two fairly independent systems for performing the two calculations (Ungerleider, 1985; Ungerleider & Mishkin, 1982). We defer discussion of this broader issue until after presenting the data from our experiments.

The paradigm that we used to study the role of location in integration processes was a variation of that used by Pollatsek et al. (1984). Subjects saw two line drawings extrafoveally that were next to each other (see Figure 1 and Table 1). When subjects made an eye movement, the two extrafoveal objects were replaced by a single meaningful object and a checkerboard pattern, respectively. In some conditions, one of the objects presented extrafoveally was identical to the meaningful foveal target object fixated after a saccade (except for a size change). In some conditions, the extrafoveal preview was in the same spatial location as the identical foveal target object, whereas in other conditions, it was in a different location (i.e., the location of the other extrafoveal object). Of

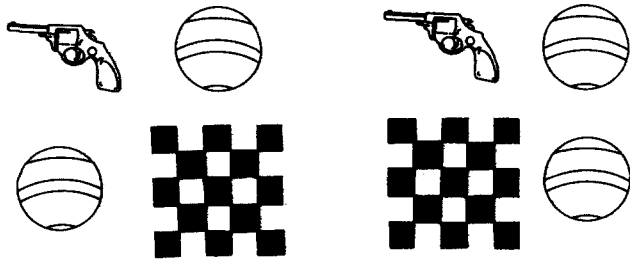


Figure 1. Examples of conditions from Experiment 1. (The left half shows the switch condition. Extrafoveally on the first fixation, the subject saw a gun and a ball. After an eye movement, on the second fixation the ball and checkerboard pattern were present in the same spatial locations, respectively. The right half shows the no-switch condition.)

crucial interest is whether the preview benefit is affected by the extrafoveal preview object when it is in the same location as the target object.

Experiment 1

The basic purpose of Experiment 1, as indicated in the previous paragraph, was to determine whether the preview benefit is different when the preview of the target picture is in a different location (*switch* condition) than when the preview of the target picture is in the same location (*no-switch* condition). We explored the switch effect in two different preview contexts. In one, the preview object that was not the target object was a different meaningful line drawing (*flanking-picture* condition), whereas in the other, the preview object that was not the target object was a square (*flanking-square* condition). These two manipulations were crossed, producing four preview conditions in which one of the preview objects was identical to the target object. In addition, there were two control conditions, one for the flanking-picture condition and one for the flanking-square condition. In the former, there

were two meaningful objects, both different from the target object, whereas in the latter, there were two squares.

Method

Subjects. Eight members of the University of Massachusetts community were paid for their participation in the experiment. They all had normal uncorrected vision and had previously been in experiments in which eye position had been monitored.

Apparatus and procedure. All the stimuli in the experiment were presented on a Hewlett-Packard cathode-ray tube (CRT) with a P-31 phosphor. The CRT has the characteristic that when a point is removed it will result in a drop to 1% of maximum brightness in 0.25 ms. Subjects rested their heads on a chin rest with an additional support for the forehead in order to minimize head movements. Eye movements were monitored via a Stanford Research Dual Purkinje Eyetracker, with spatial accuracy in the range of 10 arc min. The eye tracker and the CRT were both interfaced with a Hewlett-Packard 2100 computer, which was used both to present the stimuli and to record the eye movement and vocal latencies. The latter was recorded with a microphone whose output was amplified and fed into an analog-to-digital interface with a threshold set by the program. The signal from the eye tracker was sampled every millisecond, and the position of the eye was determined every 4 ms. When the eye moved 0.5° in the appropriate direction from the fixation point, the display change was initiated. The display change was completed in 5 ms and always occurred during the saccade when no useful visual information was extracted. Thus, the second line drawing was on the screen for about 15–20 ms before the saccade ended. Subjects never reported seeing the display change take place (although they were aware that display changes occurred).

Once subjects were adapted to the darkness, they sat in a room that was dark except for the CRT and a small light overhead. A trial consisted of the following events. First, a fixation display appeared (initiated by the experimenter) that consisted of three fixation crosses in a horizontal row: one at the left boundary of the screen, one at the right boundary of the screen, and one in the center. Subjects were instructed to look at one of the fixation crosses (either the left or right one, depending on the condition), and the experimenter checked to see if the calibration was accurate. (There was a fourth cross that moved with the computed eye position and, if the calibration was accurate, coincided with each fixation cross when the subjects looked

Table 1
Diagram of Conditions

Condition	Stimuli presented	
	Parafoveal	Foveal
Flanking picture, no switch, target inside	Alt-target	Mask-target
Flanking picture, no switch, target outside	Target-alt	Target-mask
Flanking picture, switch, target inside	Target-alt	Mask-target
Flanking picture, switch, target outside	Alt-target	Target-mask
Flanking square, no switch, target inside	Square-target	Mask-target
Flanking square, no switch, target outside	Target-square	Target-mask
Flanking square, switch, target inside	Target-square	Mask-target
Flanking square, switch, target outside	Square-target	Target-mask
Two-picture control, target inside	Alt 1-Alt 2	Mask-target
Two-picture control, target outside	Alt 1-Alt 2	Target-mask
Two-square control, target inside	Square-square	Mask-target
Two-square control, target outside	Square-square	Target-mask

Note. Table 1 represents conditions in which the preview display was presented to the left of fixation. For conditions in which the preview was to the right of fixation, the display would be a mirror image of the present display. It should be emphasized that this table represents the retinal locations of the four stimuli. Spatially, the two parafoveal stimuli and the two foveal stimuli appeared in the same location. Target = target line drawing; alt = unrelated line drawing; square = framing square; mask = checkerboard mask. See Figures 1 and 2 for examples.

thère.) If the calibration was satisfactory, as it was on most trials, the experimenter warned the subjects that a trial was to begin, and 250 ms later, the crosses were replaced by the two extrafoveal line drawings presented side by side. The subjects then moved their eyes toward the objects, and the two line drawings were replaced by the target line drawing and a checkerboard pattern presented side by side. The target pattern was in the same location as one of the extrafoveal line drawings, and the checkerboard pattern was presented in the same location as the other line drawing. The subjects then named the target line drawing and the computer recorded the latency of the vocal response from the time when the eye crossed the 0.5° threshold. The computer also recorded the latency of the eye movement as well as the location where the eye initially landed. The experimenter recorded the accuracy of the response and whether there had been a loss of tracking accuracy on that trial. If subjects did not make a correct response or if there was a track loss, the naming latency from that trial was discarded.

The subjects' eye position was calibrated at the beginning of the session and whenever necessary thereafter. At the beginning of each session, the subjects received 20 practice trials.

Stimuli and design. The line drawings were of 20 easily nameable objects and were essentially those used by Pollatsek et al. (1984). They were entered into the computer via a Summagraphics Bit-Pad. On trials in which there were two extrafoveal line drawings of objects, the pictures were visually and semantically unrelated.

In all conditions, the foveal display after the saccade was the target object and the checkerboard pattern side by side. There were six different extrafoveal preview conditions. In three, the preview was two extrafoveal pictures. In the flanking-picture no-switch condition, the extrafoveal object in the same location as the target object was identical to it, whereas in the flanking-picture switch condition, the extrafoveal object in the opposite location from the target picture was identical to it. In the control-picture condition, neither extrafoveal picture was the same as, or related to, the target object. The same pairs of extrafoveal objects were used in all three conditions so that the subjects could not know which condition it was until they fixated the second display. In two conditions, the preview was the target object and a square. In the flanking-square no-switch condition, the preview and the target were in the same location, whereas in the flanking-square switch condition, the preview and target were in opposite locations. In the control-square condition, the preview was two squares.

The target line drawings subtended 2° of visual angle horizontally and between 1° and 3° vertically and were 10% smaller than the extrafoveal previews. However, to make exposition simpler, we refer to the preview picture and target picture as identical when they were the same form but differed in size. The reason for the size change was to ensure that, when the preview and the target were in the same location, part of the preview benefit was not due to enhanced phosphor brightness of the target caused by prior excitation of the preview. Such phosphor persistence has been shown to be an artifact in some demonstrations of integration across saccades (Irwin, Yantis, & Jonides, 1983; Rayner & Pollatsek, 1983). The squares were somewhat bigger than the picture (about 2.5° on a side) and were intended to be thought of as a frame for the picture that would appear. The checkerboard pattern was the same size as the square. The two extrafoveal objects were separated by 2.5° from center to center, which was about as close as they could be put together without touching.

In one trial block, the extrafoveal objects appeared to the left of fixation, whereas in the other trial block, they appeared to the right of fixation, with the order counterbalanced across subjects. Within each trial block, the eccentricity of the extrafoveal objects was varied, with the center of the two objects being either 5° or 10° from fixation. In addition, the location of the target object was either inside (closer

to the original point of fixation) or outside (further from the original point of fixation). Thus, there were 48 conditions, resulting from a factorial $6 \times 2 \times 2 \times 2$ design, with the variables being preview condition, direction of preview objects (left vs. right), eccentricity of preview objects (5° vs. 10°), and location of target (inside vs. outside). Each of the 20 target objects was in all conditions, resulting in 960 experimental trials. Except for direction, which was blocked (as was noted earlier), the other conditions and the particular targets were randomized in a single block, resulting in two blocks of 480 trials each.

Results and Discussion

Our intention in Experiment 1 was to consider conditions in which subjects had a normal extrafoveal preview of the extrafoveal objects. Accordingly, trials in which the eye latency was less than 125 ms or greater than 400 ms were eliminated. In addition, trials were not included on which there was a loss of tracking, there was an error, or naming latency was two standard deviations from subjects' mean for that condition in that block. These accounted for 16% of the trials among them. Most of these exclusions were either track losses or eye movement anticipations, because the error rates were under 2%. The saccade latencies, which averaged about 200 ms in both Experiments 1 and 2, did not differ significantly among the preview conditions (see also Pollatsek et al., 1984); as a result, we do not discuss them further here.

The mean naming times were computed for each subject in each condition and were subjected to an analysis of variance (ANOVA). There was no main effect of direction. Although two higher order interactions of other variables with direction were significant, they were uninterpretable. Accordingly, for convenience, the means were averaged over direction and are not discussed further.

Of central importance was the difference among the six extrafoveal preview conditions, $F(5, 35) = 47.62$, $p < .001$ (see Table 2). Most of the effect was due to the objects that were in the periphery. If we took the two-square control condition as the baseline, the presence of the target object in the periphery in the flanking-square conditions (which contained the target object and a neutral square) produced a facilitation effect of about 70 ms. The presence of two objects in the periphery that were different from the target (the two-object condition) slowed naming time about 40 ms in relation to the same two-square control. On the other hand, when the target object and an irrelevant object were both in the periphery (the flanking-picture conditions), naming time was facilitated by about 15 ms. Thus, there seem to be two conflicting effects: The presence of the target in the periphery speeded naming of the target, whereas the presence of a different object in the periphery slowed naming of the target. The effects appear to be approximately additive, with the facilitation effect being a bit larger. These facilitation and inhibition effects are approximately the same as those observed in the earlier Pollatsek et al. (1984) experiments and in a series of experiments reported by Henderson, Pollatsek, and Rayner (1987).

To assess the reliability of the effects of interest, we performed several planned comparisons. In one, the two control conditions were discarded and the other four preview condi-

Table 2
Naming Latency in Milliseconds (Experiment 1)

Variable	Condition					
	Flanking picture, no switch	Flanking picture, switch	Flanking square, no switch	Flanking square, switch	Two-picture control	Two-square control
Eccentricity						
5°	768	778	685	716	840	788
10°	770	780	730	735	813	786
Mean	769	779	708	725	827	787
Target location						
Inside	727	798	688	738	813	774
Outside	810	760	727	712	841	800
Mean	769	779	708	725	827	787

tions were treated as a 2×2 factorial design (Type of Flanker \times Switch vs. No Switch). This analysis showed that the presence of extrafoveal flanking objects slowed naming time by 58 ms, $F(1, 7) = 52.35$, $p < .001$, and that when the location of the target object switched between the extrafoveal preview (Fixation 1) and the foveal display (Fixation 2), naming times were 14 ms slower, $F(1, 7) = 10.15$, $p < .025$. Although the switching effect was slightly smaller in the flanking-picture condition, the interaction of the two variables was not significant, $F(1, 7) = 3.033$, $p > .10$.

It thus appears that the integration of information from the preview depends on the relation between where that information is in the preview and when it is fixated: there was a 14-ms cost in naming time when the location of the target object was switched. This is not a huge effect, and the facilitation effect did not depend on the target object being in the same spatial location in the periphery as when in the fovea. This is seen most clearly in the 62-ms advantage of the flanking-square switch condition over the control-square condition, $F(1, 7) = 20.08$, $p < .005$.

The facilitation effect was modulated by other variables that must be discussed in order to understand the effect of the extrafoveal information. First, consider the effect of eccentricity. As can be seen in the top half of Table 2, when the extrafoveal objects were at 10° , both facilitation and inhibition effects were smaller than in the 5° condition, with the two-square control condition about the same. The Eccentricity \times Preview interaction was significant, $F(5, 35) = 14.66$, $p < .001$. There were higher order interactions involving eccentricity that had the same interpretation: Effects were smaller at 10° .

There were other significant effects of the positioning of the information besides the switch effect. As can be seen from the bottom half of Table 2, the location of the target mattered, with faster naming times when the foveal target was inside rather than outside, $F(1, 7) = 12.41$, $p < .01$. For some of the conditions, the location of the target object was confounded with the location of the preview; however, in both control conditions (two squares and two irrelevant pictures), this was not the case, and there was still a 27-ms advantage when the foveal object was in the inside. (We discuss this effect later.)

In addition, there appeared to be an effect of where the extrafoveal preview of the target was (see Table 2), because

the switching effect actually reversed when the target was on the outside. If one assumes that the effects of switching foveal target location and extrafoveal target location are additive, then an estimate of the effect of preview target location can be obtained by computing

$$\frac{1}{2} \times \{(\text{no switch, target outside}) - (\text{no switch, target inside}) + (\text{switch, target inside}) - (\text{switch, target outside})\}$$

for the flanking-square conditions. From these conditions, the best estimate is that naming times are 33 ms faster when the preview of the target object is in the inside position. This makes sense because the inside extrafoveal object is nearer to fixation and hence should be processed more fully. For the flanking-picture conditions, the advantage of the target preview being in the inside position is 61 ms. It also makes sense that the preview effect would be larger with picture flankers, because when the target is on the outside and harder to see, the interfering flanker would be on the inside and easier to see (and produce more interference). The effects of preview position were somewhat smaller at 10° than at 5° , as is reflected in a Target Position \times Target Switch \times Eccentricity interaction, $F(1, 7) = 5.404$, $p \approx .05$.

There thus appeared to be two effects due to the positioning of the information in addition to the switching effect: (a) Naming times were faster when the preview of the target object was on the inside position, and (b) naming times were faster when the target object was on the inside when viewed in the fovea. The first effect makes sense because extrafoveal information should be extracted more efficiently when it is closer to fixation. The second effect is puzzling, however, because it is not clear why the target should be processed more efficiently when it is in the same location as the inside extrafoveal position, because the subject has changed fixation to view the target.

One possible reason for the latter effect is that subjects tended to fixate closer to the inside position when the target was presented foveally (on the second fixation). In a subsidiary analysis, naming times were further classified according to whether the subjects' first fixation was nearer to the inside object or to the outside object. (Two subjects were excluded

from this analysis because they always fixated nearer the inside object.) The analysis showed the same pattern of data as that shown in Table 2, even after the location of the fixation was controlled for. In addition, the analysis showed that naming time was only 3 ms less when the subjects' fixations landed nearer the target than when they landed nearer the checkerboard pattern, $F < 1$. Thus, we have no explanation for why the position of the target affected naming time. Perhaps the inside location was usually the focus of the subjects' covert attention when the fixations landed even if the eyes did not actually land on it.

This analysis also indicates that the switching effect is not due to an eye movement artifact: Naming times could be faster in the no-switch condition if subjects tended to fixate on the spatial location of the extrafoveal target object. However, the analysis indicates that there was little benefit to fixating in the "right place." Moreover, such a strategy would require extrasensory perception in the flanking-picture conditions because there would be no way for subjects to know which of the two extrafoveal objects was going to be the target. It is possible, however, that the slightly greater switching effect in the flanking-square conditions is due to some small advantage of fixations being able to land in the right place.

What can we conclude about the process of integration of extrafoveal and foveal information from these data? First, it appears that relative location matters, because there was a switching effect. However, what is equally striking is that the extrafoveal information in the other location made a significant difference. This is shown both by the facilitation when the target preview is in the opposite location and by the inhibition when the flanking object is in the opposite location. Thus, although location matters, there is significant cross talk between the two spatial channels.

Experiment 2

As mentioned earlier, Pollatsek et al. (1984) found a smaller amount of facilitation when the extrafoveal preview was a different drawing representing the same basic concept as the target than when the preview was identical to the target. We refer to the former as *conceptual identity*.) One possibility for this difference is that visual codes are integrated in both cases but the partial mismatch in the conceptual identity condition produces less facilitation. A second possibility is that the facilitation in the conceptual identity condition does not involve visual codes at all but merely reflects activation of an amodal conceptual node in memory (Carr, McCauley, Sperber, & Parmelee, 1982; Kroll & Potter, 1984; Potter, 1979).

One way to distinguish between these possibilities is to examine the effect of location switching on the difference between facilitation when there is physical identity and facilitation when there is conceptual identity. If only semantic codes are responsible for preview benefit when the preview and target are conceptually identical, one might expect the switching effect to be reduced or even eliminated in that case. On the other hand, if visual codes are responsible for the preview benefit in both cases, then one might expect as large a switching effect when the objects are conceptually identical as when they are physically identical.

Method

Subjects. Six subjects from the University of Massachusetts community served in the experiment. They were paid for their participation, and all had uncorrected vision.

Procedure. The procedure was identical to that in Experiment 1 except as noted in the following paragraphs. As in Experiment 1, the foveal event was always the target object and the checkerboard pattern side by side.

Stimuli and design. The stimuli were those used in Pollatsek et al.'s (1984) Experiment 5. There were 10 pairs of line drawings. Each pair represented the same basic concept, but the two line drawings were representations of two different exemplars of the concept.

To simplify the design, we used only the flanking-square conditions and the two-square control conditions. As a result, there were five preview conditions: the two-square control condition, and four others in which there was one preview object and one square side by side (see Figure 2). The five preview conditions were crossed with four other conditions that resulted from a factorial combination of two variables: The location of the target object was the same as either the inside or the outside parafoveal preview location, and the preview was either physically identical to the target or conceptually identical to the target. Physical identity means that the two pictures differed only by a 10% size change, whereas conceptual identity means that the preview and foveal objects were representations of two different objects (e.g., drawings of two different cows) and also differed by the same 10% size change. For each pair of line drawings, either drawing could serve as the preview or the target in both the physical and conceptual identity conditions.

As in Experiment 1, the targets appeared equally often in the inside and outside positions with the checkerboard appearing in the other location. Also, the pair of preview objects were either 5° or 10° from fixation and either to the right or to the left of fixation. As in Experiment 1, the direction of the extrafoveal objects from fixation was blocked (with order of blocks counterbalanced across subjects), and all the other variables (preview condition, eccentricity of targets, and position of target) were randomized within blocks. Accordingly, there were two trial blocks with $20 \times 5 \times 2 \times 2 = 400$ trials in each block.

Results and Discussion

As in Experiment 1, naming latencies were used only on trials on which the subject correctly named the target object, on which there was no loss of tracking, on which naming latencies were less than two standard deviations from the subjects' mean for that condition, and on which the eye movement latency was between 125 and 400 ms. As a result, 12% of the data was excluded. (The error rate was under 2%.) Also, as in Experiment 1, the direction variable had no effect and was not considered.

There was clear facilitation in all preview conditions, with the smallest advantage over the control condition being 64 ms in the conceptual identity switch condition, $F(1, 5) = 75.57, p < .001$. As can be seen in Table 3, there were effects of both switching and of type of identity. To assess the reliability of these effects, we analyzed the data from the four preview conditions (excluding the control condition) by an ANOVA with switching and type of identity as factors. Both the 10-ms switching effect and the 16-ms advantage of physical identity over conceptual identity were significant, $F(1, 5) = 9.628, p < .05$, and $F(1, 5) = 14.91, p < .025$, respectively.

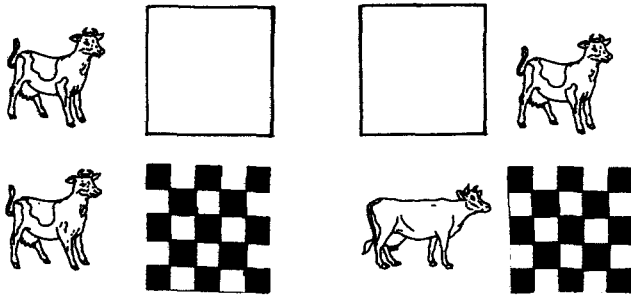


Figure 2. Examples of conditions from Experiment 2. (The left half shows an example of the physical identity no-switch condition, and the right half shows an example of the conceptual identity switch condition.)

The switch effect was slightly smaller in the conceptual identity conditions (see Table 3), although the interaction was not close to significance ($F < 1$).

As in Experiment 1, there were effects of both eccentricity and target position (see Table 3). All the facilitation effects were reduced at 10°, as reflected in a Preview Condition × Eccentricity interaction, $F(4, 20) = 5.261, p < .005$. As in Experiment 1, there was a 27-ms advantage of the target being on the inside position even in the control condition. In addition, averaging over both physical and conceptual identity, there was a 26-ms advantage for the preview of the target being on the inside position (calculated as in Experiment 1).

Thus, the data of Experiment 2 replicated all the effects observed in Experiment 1. The effects of switching the target location, the position of the target, and the position of the preview were all quite similar to those observed in the flanking-square conditions of Experiment 1. As in Experiment 1, all effects were a bit smaller at 10° than at 5°. The only difference was that the facilitation effect was slightly larger in Experiment 2 than in Experiment 1.

Experiment 3

The major question in Experiments 1 and 2 was whether the facilitating effect of extrafoveal information on the identification of a subsequently fixated object depends on the

extrafoveal information being in the same spatial location as the foveal information. The answer is a qualified yes: Although there was a small effect (about 10 ms) due to switching location, there was a sizeable preview benefit (greater than 60 ms) from the peripheral object even when the location of the object changed. Although the change in location was not particularly subtle, because there were two well-defined objects in the periphery with the relative location of the object (right vs. left) changing as well as the absolute location, the absolute size of the change in location was relatively small in the switch conditions (2.5°).

One procedure to test whether the preview benefit observed in the first two experiments would hold up under larger changes in spatial location is to present the preview as in the first two experiments but to instruct subjects not to move their eyes and subsequently present the target object foveally where they are maintaining fixation. (In other words the target object will come to the fovea of the subjects rather than the subjects needing to move their eyes to fixate it.) This *no-eye-movement* condition simulates the retinal events of the prior two experiments but creates very different spatial events: The preview and the target would be separated by either 5° or 10° of visual angle. As was mentioned in the introduction, such a no-eye-movement control condition was used in analogous experiments with words (though at smaller visual angles), and similar preview benefits were obtained as those in the condition in which the preview and target were in the same location and the eye moved to fixate the target (Rayner et al., 1978).

Method

Subjects. Six subjects from the University of Massachusetts community served in the experiment. They were paid for their participation, and all had normal uncorrected vision.

Stimuli and design. The stimuli were identical to those in Experiment 1, and the design was similar. As in Experiment 1, there were six preview conditions: flanking-picture no switch, flanking-picture switch, flanking-square no switch, flanking-square switch, two-picture control, and two-square control. These six preview conditions were crossed with the position of the target stimulus (inside vs. outside) and two levels of visual angle. Because the changed physical configuration of the trial required two objects to flank the fixation point, the fixation point had to be moved in from the edge of the screen, and it was not possible to use a 10° separation. Thus, the two visual angles used were 5° and 9.3°.

Table 3
Naming Latency in Milliseconds

Variable	Condition				
	Physical identity, no switch	Physical identity, switch	Conceptual identity, no switch	Conceptual identity, switch	Two-square control
Eccentricity					
5°	581	591	604	611	691
10°	623	636	637	645	694
Mean	602	614	621	628	692
Target location					
Inside	586	623	599	632	678
Outside	619	605	643	624	706
Mean	602	614	621	628	692

The only change in the design from Experiment 1 was that there was only one trial block. Hence, the visual field in which the peripheral stimuli appeared was varied between subjects; half the subjects saw the peripheral stimuli in the right visual field, and the other half saw them in the left visual field. As in Experiments 1 and 2, the other variables were randomized within a trial block, resulting in a single block of 480 trials: 6 (preview condition) \times 2 (target location) \times 2 (visual angle) \times 20 (target stimulus).

Procedure. The major difference between Experiments 1 and 3 was in the presentation of the stimuli. In Experiment 3, a trial consisted of the following events. A fixation cross was presented for 500 ms, after which the two peripheral preview pictures were presented for 200 ms. Simultaneous with the offset of the peripheral stimuli, the target picture and the checkerboard were presented flanking the fixation cross while the subject maintained fixation. As in Experiments 1 and 2, the subjects' task was to name the target picture as quickly as possible.

The events in Experiment 3 thus simulated the retinal events in Experiment 1 except that the subjects did not move their eyes. (In fact Table 1 represents the spatial and retinal locations of the stimuli in Experiment 3.) However, in Experiment 3, the preview and target displays were either 5° or 9.3° apart (from center to center). The value of 200 ms was chosen for the duration of the peripheral stimulus to approximate the time that those stimuli appeared before the eyes moved in Experiment 1. The simulation is approximate in one other respect. In Experiment 1, the foveal display appeared in the same location as the peripheral objects and masked them, whereas no such masking occurred in Experiment 3. We decided against masking the peripheral stimuli because we felt that (a) a mask might draw attention to the periphery and away from the foveal target and thus perhaps fundamentally change the task and (b) it was unlikely that any serious artifact would result from a mask not appearing.

Results and Discussion

As in the first two experiments, naming latencies were used only from trials on which the subjects correctly named the target object and on which the subjects' naming latency was less than two standard deviations from the mean. As a result, 1.5% of the data were excluded. Also, because there was no effect of visual field, that variable was dropped from the analysis.

Four effects in Experiment 3 were similar to those in Experiments 1 and 2. First, and most important, there was a clear facilitation effect when there was a preview of the target (see Table 4). Overall, the preview effect was 37 ms, $t(5) = 3.352$, $p < .025$, with a preview effect in the flanking-picture conditions of 32 ms (in comparison with the two-picture control), $t(5) = 3.495$, $p < .025$, and a preview effect in the flanking-square conditions of 41 ms (in comparison with the two-square control), $t(5) = 2.854$, $p < .05$. Second, the size of the preview effect was larger at 5° than at 9.3°, $t(5) = 9.322$, $p < .001$. Third, when there was a preview, subjects were faster when the preview was in the inside position (nearer fixation) than when it was in the outside position. When the preview was in the inside position, naming time was 51 ms faster in the flanking-picture conditions, $t(5) = 6.010$, $p < .005$, and 36 ms faster in the flanking-square conditions, $t(5) = 5.208$, $p < .005$. Fourth, there was an interfering effect due to the flanking pictures, with naming times being 45 ms slower when the preview appeared with a flanking picture than when it appeared with a flanking square, $t(5) = 3.868$, $p < .025$.

However, in contrast to Experiments 1 and 2, there did not appear to be any effect of the target position. When the target was on the inside position (i.e., in the same relative position as an inside preview) rather than on the outside position, naming times were 3 ms faster in the two-picture controls and 1 ms slower in the two-square controls.

Although there was a switch effect, $t(5) = 3.175$, $p < .025$, it was in the wrong direction. Subjects, on average, were 19 ms faster when the relative location of the target switched than when it did not. Because it is quite implausible that there is any intrinsic reason that switching the relative position of the object is beneficial, there must be an alternative explanation for this effect. None, however, appears to be satisfactory.

The most plausible cause of any effect due to location (other than the distance of the preview from fixation) is that preview benefit should be smaller the further the preview is from the target object that it matches. The distance between the preview and the target, however, does not explain the reversed switch effect (see the bottom half of Table 4). When the preview was closer to fixation, there was a 6-ms advantage for the target being near it (switch target outside was faster than no-switch target inside), but when the preview was farther from fixation, there was a 30-ms disadvantage for the target being near it (no-switch target outside was slower than switch target inside). Although one can always come up with an ad hoc explanation for the latter effect (e.g., objects at the extrema of the display are more salient, causing faster processing), it does not seem like a fruitful endeavor.

Because the antiswitch effect appears to be an enigma, the conclusions one can draw from it are limited. At the least, it indicates that the benefit that accrues from the preview being in the same relative location as the target does not extend to these no-eye-movement conditions in which the preview and target displays are far apart.

Experiment 4

The pattern of results in Experiment 3 was thus similar to those in Experiments 1 and 2, suggesting that eye movements are largely irrelevant to the integration process being studied. There were two ways, however, in which the data of Experiment 3 differed from those of Experiments 1 and 2: The switch effect reversed, and there was no effect due to the position of the target object. Because it was unclear why subjects in Experiments 1 and 2 showed a target location effect in the first place, it is unclear what conclusions can be drawn from the difference. In contrast, the fact that the switch effect disappeared suggests that relative location is relevant when an eye movement occurs but is not relevant when no eye movement occurs. There was a second important difference between Experiments 1 and 2 and Experiment 3, however: The pair of objects were in the same spatial location in Experiments 1 and 2 but not in Experiment 3. Thus, we do not know whether the loss of the switch effect in Experiment 3 was due to the lack of an eye movement or to the change in spatial location. To remedy this situation, we ran a fourth experiment in which both the preview and target displays were presented foveally. Thus, the preview and target were in

Table 4
Naming Latency in Milliseconds (Experiment 3)

Variable	Condition					
	Flanking picture, no switch	Flanking picture, switch	Flanking square, no switch	Flanking square, switch	Two-picture control	Two-square control
Eccentricity						
5°	754	719	677	675	786	741
10°	740	742	730	690	755	727
Mean	747	730	704	682	771	734
Target location						
Inside	717	751	680	694	769	735
Outside	777	714	728	671	772	734
Mean	747	730	704	682	771	734

both the same retinal and spatial location, and no eye movement intervened between the preview and target objects.

Method

Subjects. Eight subjects from the University of Massachusetts community served in the experiment. They were paid for their participation, and all had normal uncorrected vision.

Stimuli and design. The stimuli were identical to those used in Experiment 3, and the design was similar. However, the flanking-square preview conditions were dropped, because we thought that subjects might begin to name the preview when it was presented foveally accompanied only by a square. Thus in Experiment 4, there were four preview conditions: flanking-picture no switch, flanking-picture switch, two-picture control, and two-square control. These four preview conditions were crossed with the position of the target stimulus (left vs. right). Conditions and stimuli were randomized within a trial block, resulting in a single block of 160 trials: 4 (preview condition) \times 2 (target location) \times 20 (target stimulus). All displays were centered around the center of the screen.

Procedure. The only difference between Experiments 3 and 4 was the location of the preview. As in Experiment 3, a trial consisted of the following events: A fixation cross was presented for 500 ms, after which the two preview pictures were presented centered around the fixation cross for 200 ms. Simultaneous with the offset of the preview stimuli, the target picture and the checkerboard were presented in the same locations while the subject maintained fixation. As in the prior experiments, the subjects' task was to name the target picture as quickly as possible.

Results and Discussion

As in the first three experiments, naming latencies were used only from trials on which the subjects correctly named the target object and on which the subjects' naming latency was less than two standard deviations from the mean. As a result, 2.5% of the data were excluded. The position of the target (left vs. right) had no effect and did not interact with any other variable (all $F_s < 1$) and thus is not considered further.

Of central interest in Experiment 4 was whether there was a preview effect and whether there was a switch effect. The best measure of the preview effect is the two-picture control minus the average of the flanking-picture conditions (see Table 5). The value of this contrast was 68 ms, $t(7) = 4.312$,

$p < .005$. Furthermore, both the no-switch and switch conditions showed facilitation relative to this control, $t(7) = 5.298$, $p < .001$, and $t(7) = 2.650$, $p < .05$, respectively. Thus, there was a preview effect in this experiment similar to that in the prior experiments. However, as can be seen from Table 5, the preview conditions were not faster than the two-square control, with the average of the two preview conditions actually 14 ms slower than the two-picture control, $t \approx 1$. In addition, there was a switch effect of 40 ms, $t(7) = 2.756$, $p < .025$. Thus, the lack of a switch effect in Experiment 3 was apparently due to the difference in spatial location of the preview and target arrays rather than to the absence of a saccade between the preview and the target.

General Discussion

The major results of the four experiments are summarized in Table 6. Of primary interest was the finding that there was a preview benefit in all four experiments; that is, a preview aided object naming regardless of whether a saccade intervened between preview and target (Experiments 1 and 2 vs. Experiments 3 and 4) and regardless of whether the target was in the same approximate location (Experiments 1, 2, and 4) or 5° or more apart (Experiment 3). In addition, there was a small advantage when the preview and target were in the same relative location in the display, but only when they were also in the same spatial location as well (Experiments 1, 2, and 4). Furthermore, there was still a substantial preview benefit in all experiments even when the location of the preview was not the same as the location of the target. These findings indicate that the processes responsible for the integration of object information operate in substantially the same manner within and across fixations but may operate somewhat differently when the preview and target are widely separated in space.

Table 5
Naming Latency in Milliseconds (Experiment 4)

Condition	Latency
Flanking picture no switch	763
Flanking picture switch	803
Two picture control	851
Two square control	769

Table 6
Summary of Experiments 1-4

Experiment	Condition	Preview benefit	Switch effect
1	Flanking picture	53	10
1	Flanking square	70	17
2	Flanking square, same form	88	12
2	Flanking square, different form	67	7
3	Flanking picture	33	-17
3	Flanking square	41	-22
4	Flanking picture	68	40

A striking difference across the experiments was the reversed switch effect in Experiment 3, for which we have no explanation. There was also a suggestion that the preview effect was a bit less in Experiment 3 (see Table 6). This could be due to the requirement that subjects maintain fixation while observing an extrafoveal object. Perhaps subjects might not be able to attend to the preview objects as well in this circumstance as when they are about to make an eye movement to it (see below). The preview and switch effects appeared to be somewhat larger in Experiment 4 than in Experiments 1 and 2. This makes sense, because both the information about the preview objects and about spatial location should be registered more strongly in the fovea, because the quality of the visual information is higher there.

There are likely to be limits, though, on when a preview of an object benefits identification when it is later fixated. For example, Rayner et al. (1978) presented a random string of letters to one side of fixation and a word to the other side of fixation. Subjects were instructed to move their eyes to a particular side on each trial, and a target word appeared in the location of the preview on the side to which they moved. Rayner et al. found that a preview benefit occurred only when the preview was on the same side of fixation as the target. However, the paradigm changes more than the distance between the two objects; shifts of covert attention are probably involved as well. That is, when the eyes move to a location in space, there is reason to believe that a shift of covert attention precedes the eye movement (Inhoff, Pollatsek, Posner, & Rayner, 1989; Morrison, 1984; Wurtz, Goldberg, & Robinson, 1980). Thus, if the two objects are separated widely in space, it is possible that subjects attend only to the object that is about to be fixated. If so, there may be no facilitation in such cases, because the extrafoveal information from the unattended location was not extracted in the first place rather than because integration cannot occur between information coming from such disparate spatial locations.

By analogy, it seems likely that if the two extrafoveal pictures were separated by a large distance (e.g., one was 5° to the right and the other 5° to the left of fixation), there would be little preview benefit if the preview and target appeared in different locations. Although that experiment has not been conducted, a similar result has been obtained by Henderson, Pollatsek, and Rayner (1989). In one of their experiments, four pictures were arranged in an imaginary square, with the centers of the adjacent pictures 5° apart. Subjects were instructed to fixate the pictures in turn in order to be able to answer an immediate memory question, and the

index of processing time for an object was the fixation time on that object. In one condition, subjects had all four pictures available on each fixation, whereas in another, they merely had available the picture they were fixating and the picture to be fixated next (the other pictures were replaced with meaningless blobs). The fixation times on the objects in the two conditions did not differ significantly, indicating that there was little or no preview benefit from an object unless it was about to be fixated.

Possible Models of Information Integration

A priori, there appear to be two basic schemes for integration of object information across saccades. The first is that there is an object file of visual (and perhaps nonvisual) features set up for each object in the visual field, with the object files organized by spatial location of the feature bundles. After a saccade, new featural information at a spatial location would presumably be added to the old information until sufficient information is present to identify the object. Such a model appears to be untenable given the present data, because it would predict little integration of information in the flanking-square condition when the target object position is switched (because a new file would have to be created) but would predict large amounts of interference in the flanking-picture condition when the target object position is switched (because inconsistent information would be integrated from the two pictures).

One could attempt to patch such a model by imposing a preprocessing stage at the beginning of each fixation that would determine whether the information at a given target location was the same or different; if it was the same, the new information would be added to the old (as before), but if the new information at a location was judged as different, the processor would search for another object file that was the same as the old object file or, failing that, would create a new object file at that spatial location. Such a patch seems quite unsatisfactory. First, the judgment of same or different should take a substantial amount of time, because appreciable new information would need to accumulate in order to determine sameness. (Because there is substantial facilitation even when the pictures are physically different but conceptually similar, this judgment would need to be more sophisticated than detection of a mismatch on a single physical feature.) Moreover, it seems implausible that the search process for a new object file would take only about 10 ms (the switch effect).

Instead, it appears that the file in which information is integrated is organized largely independent of position information. Let us sketch one possible model. We assume that there are detectors (analogous to cognitive demons in a pandemonium model) that fire optimally when a certain object appears anywhere in the visual field. However, objects that are visually similar to the object that is present also cause detectors to fire, but to a lesser extent. We are vague about the level of specificity of such object detectors but require that they be more specific than that of a basic concept such as *dog*, because there is less benefit from a preview of a different exemplar of the same concept than from a preview of an identical exemplar. We also remain vague about whether such detectors are fed by an earlier level of feature detectors, by a sophisticated template system (e.g., Trehub, 1977), or by a more complex initial preprocessing system (e.g., Marr, 1982). Presumably, such specific object detectors would all excite more general basic concept detectors at the next level. An object is presumably identified when sufficient excitation in a file is reached. We are also vague about whether sufficient excitation is with respect to an absolute threshold or to the level of excitation of other object files in memory. Finally, because objects can be localized in space, we assume that an object file is tagged with its appropriate spatial location.

We assume that subjects access the appropriate name by interrogating the object files guided both by the appropriate spatial tag and by the relative levels of excitation in the object files. If there is only one object file highly excited (as in the flanking-square preview or two-square control conditions), search time is reduced in relation to when there is more than one object file excited (as in the flanking-picture preview or two-picture control conditions). Similarly, if the location of the object changes, there will be two location tags associated with the file (although the tag for the current location should be stronger), causing interference in relation to when there is only one location tag associated with the target object. To explain the switch effect observed here, we need to postulate that this tag's spatial location is defined in terms of body coordinates rather than in terms of relative location (e.g., "the object on the left").

The preceding paragraph does not specify how relative strength in files and spatial location tag guide search. The data constrain the possibilities, however. Because the switch effect was no smaller when a competing object was missing than when it was present, it appears that the lack of a competing object does not allow the use of a spatial tag to be short-circuited. Thus, either the two cues are used in parallel or they are used in a serial-exhaustive fashion.

In summary, the data seem most parsimoniously explained by a model in which the object identification process is performed by detectors that are not themselves organized by spatial location and that are only indirectly tagged with the appropriate spatial location of the target. There is other evidence supporting this view. First, consider what is currently known about the architecture of the monkey visual system. One of the important discoveries in the past decade is that there are multiple retinotopic (or spatiotopic) maps in which visual information is represented (e.g., Cowey, 1981). The function of many of these areas is poorly understood; how-

ever, the only kind of information known to be coded in these areas are what could be thought of as crude visual features. In contrast, the cortical region in which there is evidence for detectors of relatively complex patterns (monkey's paw and monkey's face) is not spatiotopically organized (Gross & Mishkin, 1977; Schwartz, Desimone, Albright, & Gross, 1985). Moreover, at least some of these detectors are more specific than generic concepts (e.g., cells seem "tuned" to a monkey's face in different views). This architecture makes sense, because it would seem that an unreasonably large storage capacity within a single spatiotopic representation is required in order to represent accurately the spatial position and the many potential objects in that location. Instead, it would seem more reasonable to have one storage area that codes for the category of the object present and then have pointers to identify this category label with spatiotopically organized lower level visual featural information. In addition, there is evidence from discrimination experiments with monkeys that lesions in an occipital-parietal pathway interfere selectively with tasks based on location information, whereas lesions in an occipital-temporal pathway interfere selectively with tasks based on object identification (Ungerleider & Mishkin, 1982).

The conclusion that position information is only marginally relevant to integrating object information across saccades is consonant with work on iconic memory, indicating that the benefit of a spatially defined partial report cue disappears rapidly. In the classic Sperling (1960) experiments, the partial report advantage declined sharply in the first 100 ms and disappeared by 300 ms. Because a saccade in our experiment lasted about 30–50 ms, one would expect rapid decay of the spatial information from the visual stimulus on the first fixation even if there were no stimulus after the beginning of the saccade that might help to mask out the spatial information. However, there is currently some controversy about the interpretation of the partial report advantage. Some accounts (Dick, 1969; DiLollo, 1977; Dixon, 1986; Mewhort, Campbell, Marchetti, & Campbell, 1981; Townsend, 1973) posit that the readout of characters is from a postcategorical memory in which spatial location is represented but in which the spatial information decays rapidly. Other accounts (Irwin & Brown, 1987) maintain that the spatial information readout of the low-level visual buffer may be maintained in the postcategorical memory for periods of 500 ms or longer. The latter interpretation seems more reasonable, because we clearly can localize objects more than half a second after the visual stimulation has disappeared. However, the rapid decline of the partial report advantage suggests that the spatial information that remains may be coded differently and may be ineffective in guiding perceptual processing.

In conclusion, it appears that integration of information across fixations is somewhat insensitive to the relative location of the information on the two fixations. This is consonant with earlier findings (Pollatsek et al., 1984) that most of the benefit of previews is going on at a relatively high level. Our primary focus in this article is on the information that is maintained and utilized across fixations. In principle, it might be possible that there is some information that does not survive a saccade and that other information does and is used

on the following fixation. However, we found that when processing line drawings, subjects appear to integrate information within a fixation in the same way they integrate information across successive fixations (at least when there is some perceptible change in the display). Earlier experiments (Rayner et al., 1978) indicated the same to be true for processing text. Our model is one instantiation of how object information may be stored and accessed after a saccade, or after a change in the display within a saccade.

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