# Research Article

## TO SEE OR NOT TO SEE: The Need for Attention to Perceive Changes in Scenes

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**Abstract**—*When looking at a scene, observers feel that they see its entire structure in great detail and can immediately notice any changes in it However, when brief blank fields are placed between alternating displays of an original and a modified scene, a striking failure of perception is induced Identification of changes becomes extremely difficult, even when changes are large and made repeatedly Identification is much faster when a verbal cue is provided showing that poor visibility is not the cause of this difficulty Identification is also faster for objects considered to be important in the scene These results support the idea that observers never form a complete, detailed representation of their surroundings In addition, the results indicate that attention is required to perceive change, and that in the absence of localized motion signals attention is guided on the basis of high-level interest*

Although people must look in order to see looking by itself is not enough For example, a person who turns his or her eyes toward a bird singing in a tree will often fail to see it right away, latching onto it only after some effort This also holds true for objects in plain view A driver whose mind wanders can often miss important road signs, even when these are highly visible In both situations, the information needed for perception is available to the observer Something, however, prevents the observer from using this information to see the new objects that have entered the field of view

In this article, we argue that the key factor is attention In particular, we propose that the visual perception of change in a scene occurs only when focused attention is given to the part being changed In support of this position, we show that when the low-level cues that draw attention are swamped, large changes in images of real-world scenes become extremely difficult to identify, even if these changes are repeated dozens of times and observers have been told to expect them Changes are easily identified, however, when a valid verbal cue is given, indicating that stimulus visibility is not reduced Changes are also easily identified when made to objects considered to be important in the scene Taken together, these results indicate that—even when sufficient viewing time has been given—an observer does not build up a representation of a scene that allows him or her to perceive change automatically Rather, perception of change is mediated through a narrow attentional bottleneck, with attention attracted to various parts of a scene based on high-level interest

The phenomenon of *induced change blindness* has previously been encountered in two rather different experimental paradigms The first, concerned with visual memory, was used to investigate the detection of change in briefly presented arrays of simple figures or letters (e g , Pashler, 1988, Phillips, 1974) An initial display was presented for 100 to 500 ms, followed by a brief interstimulus interval (ISI), followed by a second display in which one of the items was removed or replaced on half the trials Responses were forced-choice guesses about whether a change had occurred Observers were found to be poor at detecting change if old and new displays were separated by an ISI of more than 60 to 70 ms

The second type of paradigm, stemming from eye movement studies, was used to examine the ability of observers to detect changes in an image made during a saccade (e g , Bridgeman, Hendry, & Stark, 1975 Grimes, 1996, McConkie & Zola, 1979) A variety of stimuli were tested, ranging from arrays of letters to images of real-world scenes In all cases, observers were found to be quite poor at detecting change, with detection good only for a change in the saccade target (Currie, McConkie, Carlson-Radvansky, & Irwin, 1995)

Although blindness to saccade-contingent change has been attributed to saccade-specific mechanisms, the blurring of the retinal image during the saccade also masks the transient motion signals that normally accompany an image change Because transients play a large role in drawing attention (e g , Klein Kingstone, & Pontefract, 1992, Posner, 1980), saccade-contingent change blindness may not be due to saccade-specific mechanisms, but rather may originate from a failure to allocate attention correctly The blindness to changes in briefly presented displays may have a similar cause In those experiments detection was not completely at chance, but instead was at a level corresponding to a monitoring of four to five randomly selected items, a value similar to the number of items that can be attended simultaneously (Pashler, 1987, Pylyshyn & Storm, 1988, Wolfe, Cave, & Franzel, 1989)

In order to examine whether both types of change blindness might be due to the same attentional mechanism, and whether this mechanism might also lead to change blindness under more normal viewing conditions, we developed a *flicker paradigm* In this paradigm, an original image A repeatedly alternates with a modified image A', with brief blank fields placed between successive images (Fig 1) Differences between the original and modified images can be of any size and type (In the experiments presented here, the changes were chosen to be highly visible ) The observer freely views the flickering display and hits a key when the change is perceived To prevent guessing, we ask the observer to report the type of change and describe the part of the scene that was changing

This paradigm allows the ISI manipulations of the brief-display techniques to be combined with the free-viewing conditions and perceptual criteria of the saccade-contingent methods And because the stimuli are available for long stretches of time and no eye movements are required, the paradigm also provides the best opportunity possible for an observer to build a representation conducive to perceiving changes in a scene The change blindness found with the brief-display techniques might have been caused by insufficient time to build an adequate representation of the scene, saccade-contingent chang

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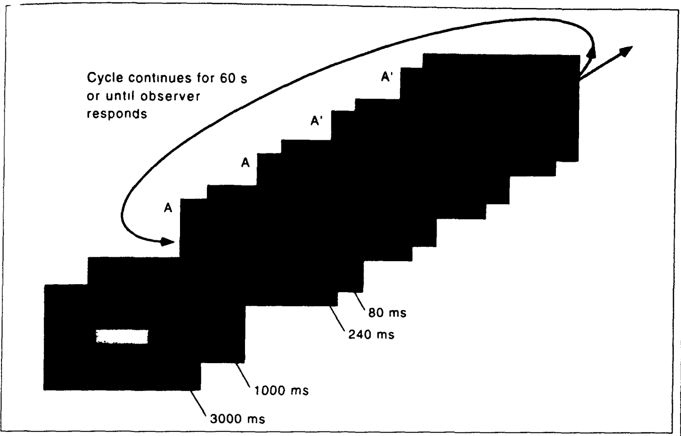


**Fig 1** General design of the flicker paradigm Trials began with a 3-s gray field containing a white rectangle (in which a word appeared when a cue was used) This was followed by a 1-s gray field, followed by a flicker sequence that continued until the observer responded or 60 s had elapsed In the example here, original image A (statue with background wall) and modified image A' (statue with wall removed) are displayed in the order A, A, A', A', , with gray fields between successive images

blindness might have been caused by disruptions due to eye movements Both of these factors are eliminated in the flicker paradigm, so that if they were indeed the cause of the difficulties in the other paradigms, perception of change in the flicker paradigm should be easy But if attention is the key factor, a different outcome would be expected The flicker caused by the blank fields would swamp the local motion signals due to the image change preventing attention from being drawn to its location Observers would then fail to see large changes under conditions of extended free viewing, even when these changes were not synchronized to saccades

## GENERAL METHOD

In the experiments reported here, flicker sequences were usually composed of an original image A and modified version A' displayed in the sequence A, A, A', A', , with gray blank fields placed between successive images (Fig 1) Each image was displayed for 240 ms and each blank for 80 ms Note that each image was presented twice before being switched This procedure created a degree of temporal uncertainty as to when the change was being made, and also allowed for a wider range of experimental manipulation

All the experiments used the same set of 48 color images of real-world scenes Images were 27° wide and 18° high A single change—a color, location, or presence versus absence—was made to an object or area in each To test for the influence of higher level factors, we divided changes further according to the degree of interest in the part of the scene being changed Interest was determined via an independent experiment in which five naive observers provided a brief verbal description of each scene *Central interests* (CIs) were defined as objects or areas mentioned by three or more observers, *marginal interests* (MIs) were objects or areas mentioned by none The average changes in intensity and color were similar for the MIs and the CIs, but the areas of the MI changes (average = 22 sq deg) were somewhat larger than the areas of the CI changes (average = 18 sq deg) In all cases, changes were quite large and easy to see once noticed For example, a prominent object could appear and disappear, switch its color between blue and red, or shift its position by a few degrees (Fig 2)

Ten naive observers participated in each experiment They were instructed to press a key when they saw the change, and then to describe it verbally Before each experiment, observers were told of the types of change possible, and were given six practice trials (two examples of each type) to familiarize themselves with the task Images were presented in random order for each subject The dependent variable was the average number of alternations (proportional to the reaction time) needed to see the change Averages were taken only from correct responses (i e , responses in which the observer correctly identified both the type of change occurring and the object or area being



 

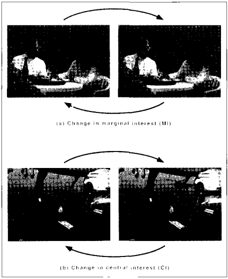


**Fig. 2.** Examples of changes in scenes. Original and modified images alternated every 640 ms. A change in a marginal interest is illustrated by the changed position of the railing behind the people in (a). Although the railing is easily seen, and its location shift is large (3°), an average of 16.2 alternations (10.4 s) was required for identification. A change in a central interest is illustrated by the changed position of the helicopter in (b). Although the change in location is roughly the same as in (a), and the size and contrast of the items changed are comparable, identification of the change in (b) required on average only 4.0 alternations (2.6 s).

changed). As might be expected given the large changes, identification error rates were low, averaging only 1.2% across the experiments.

## EXPERIMENT 1

Experiment 1 examined whether the basic flicker paradigm could indeed induce change blindness. Images were displayed for 240 ms and blanks for 80 ms, with images repeated before being switched (Fig. 1). If insufficient viewing time were the reason for the change blindness found in the brief-display experiments, we expected changes in this experiment to be seen within at most a few seconds of viewing. If saccade-specific mechanisms were responsible for the change blindness found in the saccade experiments, we expected changes in this experiment to be easy to see simply by keeping the eyes still. But if the failures to detect change in the previous paradigms were due to an attentional mechanism, we expected changes under these flicker conditions to take a long time to see.

The results of Experiment 1 (Fig. 3a) show a striking effect. Under flicker conditions, changes in MIs were extremely difficult to see, requiring an average of 17.1 alternations (10.9 s) before being identified; indeed, for some images, observers required more than 80 alternations (50 s) to identify a change that was obvious once noticed. Changes in CIs were noticed much more quickly, after an average of 7.3 alternations (4.7 s). Because discriminability was not equated for the three different types of change, performance between them cannot be compared. However, within each type of change, perception of MI changes took significantly longer than perception of CI changes ($p < .001$ for presence vs. absence; $p < .05$ for color; $p < .001$ for location), even though MI changes were on average more than 20% larger in area.

To confirm that the changes in the pictures were indeed easy to see when flicker was absent, the experiment was repeated with the blanks in the displays removed. A completely different pattern of results emerged: Identification required only 1.4 alternations (0.9 s) on average, showing that observers noticed the changes quickly. No significant differences were found between MIs and CIs for any type of change, and no significant differences were found between types of change ($p > .3$ for all comparisons).

## EXPERIMENT 2

One explanation for the poor performance found in Experiment 1 might be that old and new scene descriptions could not be compared because of time limitations. Although the blanks between images lasted only 80 ms—well within the 300-ms duration of iconic memory (e.g., Irwin, 1991; Sperling, 1960)—it has been shown that approximately 400 ms are needed to process and consolidate an image in memory (Potter, 1976). The images in Experiment 1 were displayed for only 240 ms, which may have interfered with consolidation, and thus with the ability to compare successive images.

In Experiment 2, therefore, the blanks between pairs of identical images were "filled in" by replacing them with an 80-ms presentation of the "surrounding" images. Thus, instead of presenting each image for 240 ms, followed by a blank for 80 ms, and then presenting it again for another 240 ms, we presented images without interruption for 560 ms (240 + 80 + 240) at a time. Because the blanks between the original and modified images were kept, original image A and modified image A′ were now presented in the sequence A, A′, A, A′ . . . , with changes continuing to be made at the same rate as before. If memory processing were the limiting factor, the longer display of the images in this experiment should have allowed consolidation to take place, and so caused the changes to be much more easily seen.

The results (Fig. 3b), however, show that this did not occur. Although there was a slight speedup for MI changes, this was not large; indeed, response times for MIs and CIs for all three kinds of change were not significantly different from their counterparts in Experiment 1. Note that these results also show that the temporal uncertainty caused by the repeating images in Experiment 1 does not affect performance greatly: Pairs of identical 240-ms images separated by 80 ms have much the same effect as a single image presented for 560 ms.

## EXPERIMENT 3

Another possible explanation for the occurrence of change blindness under flicker conditions is that the flicker reduces the visibility of the items in the image to the point where they simply become difficult to see. To examine this possibility, in Experiment 3 we repeated Experiment 1, but with a verbal cue (single word or word pair) placed in a white rectangle for 3 s at the beginning of each trial. Two different

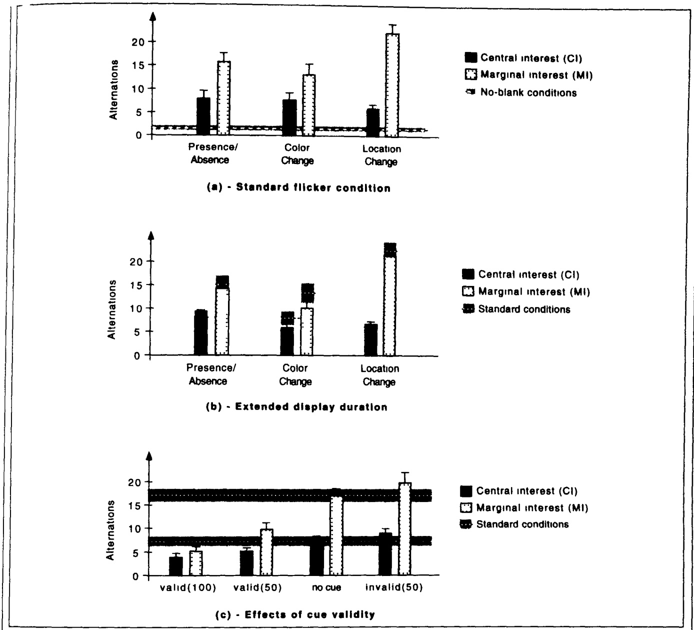


**Fig. 3.** Identification of change under flicker conditions. Error bars indicate one standard error; the shaded areas surrounding the dashed lines indicate the standard errors of comparison conditions. Results under the basic conditions of Experiment 1 are shown in (a). The dashed line indicates baseline performance when no blanks are present. The effect of longer image duration is shown in (b). The dashed lines indicate the results of Experiment 1. The effects of verbal cues are shown in (c). Valid cues were presented on 100% and 50% of the trials in the completely and partially valid cue conditions, respectively. These cues are referred to as "valid(100)" and "valid(50)" in the graph. Invalid cues were presented on 50% of the trials in the partially valid condition. These cues are referred to as "invalid(50)" in the graph.

cuing conditions were used. In the *partially valid* condition, cues were divided equally into valid cues (naming the part of the scene changed) and invalid cues (naming some other part). In the *completely valid* condition, cues were always valid. If visibility is indeed the limiting factor, no large effect of cuing should have occurred—the target would simply remain difficult to find. Otherwise, performance should have been greatly sped up by valid cues, and relatively unaffected (or even slowed down) by invalid ones.

As Figure 3c shows, valid cues always caused identification of both MI and CI changes to be greatly sped up. This speedup was significant for both the partially valid condition ($p < .001$ for MI, $p < .03$ for CI) and the completely valid condition ($p < .001$ for both MI and CI). Indeed, in the completely valid condition, the difference in response times for MIs and CIs declined to the point where it was no longer significant. Note that this latter result indicates that the faster performance for CIs in Experiment 1 is unlikely to be due to the simple salience of their features. Such a near-equality of search times would hardly be expected if the CIs contained features salient enough to preferentially catch the attention of observers.

In contrast to valid cues, invalid cues caused a slight slowdown in performance (although this was not found to be significant). Taken together, then, these results show that observers could readily locate a cued target under flicker conditions, thereby demonstrating that visibility was not a limiting factor.

## GENERAL DISCUSSION

The preceding experiments show that under flicker conditions, observers can take a surprisingly long time to perceive large changes in images of real-world scenes. This difficulty is due neither to a disruption of the information received nor to a disruption of its storage. It does, however, depend greatly on the significance of the part of the scene being changed, with identification being faster for structures of central interest than for those of marginal interest.

We therefore make the following proposal:

- Visual perception of change in an object occurs only when that object is given focused attention;
- In the absence of focused attention, the contents of visual memory are simply overwritten (i.e., replaced) by subsequent stimuli, and so cannot be used to make comparisons.

Although it is not yet possible to specify the detailed operation of the attentional mechanisms involved, it is likely that the allocation of attention causes the relevant structures to form *object files* (Kahneman, Treisman, & Gibbs, 1992), or at least lets them be entered into a relatively durable store, such as visual short-term memory (e.g., Coltheart, 1980; Irwin, 1991; Sperling, 1960), so that comparisons can be made.

In this view, all the effects encountered in these experiments can be traced back to the allocation of attention, which is either "pulled" by transient motions or "pushed" by volitional control (e.g., Klein et al., 1992; Posner, 1980). Under normal conditions, the motion signals resulting from a change draw attention to its location and so allow the observer to perceive it. When these signals are delocalized by flicker, their influence is effectively removed: attention is then directed entirely by static low-level properties such as feature gradients (Nothdurft, 1992) and high-level volition. If there are no distinct low- or high-level cues (true of most stimuli we used), detection of change will require a slow, item-by-item scan of the entire image, giving rise to long identification times. The faster identification of CI than MI changes despite the smaller area of the CI changes—would result from the attraction of attention via the high-level interest of CI objects.

If this view is correct, it points toward tighter connections between lines of research in four rather different areas of vision: eye movements, visual attention, visual memory, and scene perception. For example, the failure to find representations capable of providing automatic detection of change supports the view of eye movement researchers (e.g., Bridgeman et al., 1975; Irwin, 1991; McConkie & Zola, 1979) that there simply is no spatiotopic buffer where successive fixations are added, compared, or otherwise combined. Note that although our experiments did not explicitly address the issue of image addition (superposition), the difficulty in detecting positional shifts suggests that such superposition is unlikely; otherwise, observers could simply have looked for instances of doubled structures (i.e., images in which the original and the shifted object were both present side by side). In any event, it appears that much—if not all—of the blindness to saccade-contingent change is simply due to the disruption of the retinal image during a saccade, which causes swamping of the local motion signals that would normally draw attention. A similar explanation can also account for the change blindness encountered in the brief-display studies, suggesting that a common framework may encompass both of these effects.

The results presented here are also related to studies finding (Mack, Tang, Tuma, Kahn, & Rock, 1992; Neisser & Becklen, 1975; Rock, Linnett, Grant, & Mack, 1992) that attention is required to explicitly perceive a stimulus in the visual field. In those studies, observers giving their complete attention to particular objects or events in a scene became "blind" to other, irrelevant objects. This effect required that observers not suspect that the irrelevant objects would be tested, for even a small amount of (distributed) attention would cause these objects to be perceived. The present results are more robust, in that blindness occurred even when observers knew that changes would be made, and so could distribute their attention over the entire picture array if it would help. Thus, although distributed attention apparently facilitates the perception of object presence, it does not facilitate the perception of change. Presumably, distributed attention is not sufficient to move a structure from visual memory into the more durable store that would allow the perception of change to take place.

In addition to proposing that attended items are entered into a relatively stable store, we propose that unattended items are overwritten by new stimuli that subsequently appear in their location. This latter point is based on the finding that change blindness occurs even when images are separated by an ISI of only 80 ms, a time well within the 300-ms limit of iconic memory; if no such replacement took place, observers could simply have used the superposed images of original and shifted objects to find positional shifts. Such a replacement of unattended items has been proposed to explain metacontrast masking (Enns & DiLollo, 1997), and it is possible that the same mechanism is involved in the change blindness we observed. In any event, this mechanism implies that two rather different fates await items in visual memory: Attended items are loaded into a durable store and are perceived to undergo transformation whenever they are changed, whereas unattended items are simply replaced by the arrival of new items, with no awareness that replacement has occurred.

Finally, the work presented here also suggests a tighter connection between attention and scene perception. Recall that the valid cues in Experiment 3 caused performance to be greatly sped up. It could be argued that looking for change induces a coding strategy quite different from that of normal viewing; for example, when observers search for a cued object, attention might be more fully engaged and so might "weld" visual representations into a form more suitable for detecting change. But the invalid cues did not help at all, showing that attentional scanning of this kind does not by itself cause any increase in speed.

This result indicates that perception of change is not helped by a person's having attended to an object at some point in its past. Rather, the perception of change can occur only during the time that the object is being attended (or at least during the time it is held in the limited-capacity durable store). After attention is removed, the perception of change vanishes, and any previously attended items again become susceptible to replacement. A similar evaporation of attentional effect has been found in visual search, in which feature conjunctions appear to obtain no benefit from having been previously attended (Wolfe, 1996). Thus, just as the detailed perception of a scene is mediated by a rapidly shifting fovea of limited area, so is it also mediated by a rapidly shifting attentional mechanism limited in the number of items it can handle at any one time.

The limited capacity of this mechanism requires that it be used effectively if a scene is to be perceived quickly. But how can appropriate guidance be given if the scene has not yet been recognized? Previous work has shown that the gist of a scene can be determined within 100 to 150 ms (Biederman, Mezzanotte, & Rabinowitz, 1982; Intraub, 1981; Potter, 1976); it may well be that the gist includes a description of the most interesting aspects, which are then used to guide attention. By measuring the relative speed of perceiving changes to various parts of a scene, researchers might be able to determine the order in which attention visits the constituent objects and regions. The resultant "attentional scan path" may prove to be an interesting new tool in the study of scene perception, providing a useful complement to techniques that study eye movements and memory for objects as a function of how well they fit the gist of a scene (e.g., Friedman, 1979; Loftus & Mackworth, 1978). Furthermore, the correlation we found between reaction time and degree of interest (as derived from written descriptions) opens up another interesting possibility, namely, that the flicker paradigm can be adapted to determine what nonverbal observers (e.g., animals and young children) find interesting in the world.

Why can people look at but not always see objects that come into their field of view? The evidence presented here indicates that the key factor is attention, without which observers are blind to change. The fact that attention can be concurrently allocated to only a few items (e.g., Pashler, 1987; Pylyshyn & Storm, 1988; Wolfe et al., 1989) implies that only a few changes can be perceived at any time. Although such a low-capacity mechanism might seem to be rather limiting, this need not be the case: If it can switch quickly enough so that objects and events can be analyzed whenever needed, little is gained by the simultaneous representation of all their details (Ballard, Hayhoe, & Whitehead, 1992; Dennett, 1991; O'Regan, 1992; Stroud, 1955). Thus, given that attention is normally drawn to any change in a scene and is also attracted to those parts most relevant for the task at hand, the subjective impression of an observer will generally be of a richly detailed environment, with accurate representation of those aspects of greatest importance. It is only when low-level transients are masked or are disregarded because of inappropriate high-level control that the management of this dynamic representation breaks down, causing its relatively sparse nature to become apparent.

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## REFERENCES

Ballard, D.H., Hayhoe, M.M., & Whitehead, S.D. (1992). Hand-eye coordination during sequential tasks. *Philosophical Transactions of the Royal Society of London B, 337,* 331–339.

Biederman, I., Mezzanotte, R.J., & Rabinowitz, J.C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology, 14,* 143–177.

Bridgeman, B., Hendry, D., & Stark, L. (1975). Failure to detect displacements of the visual world during saccadic eye movements. *Vision Research, 15,* 719–722.

Coltheart, M. (1980). Iconic memory and visible persistence. *Perception & Psychophysics, 27,* 183–228.

Currie, C., McConkie, G.W., Carlson-Radvansky, L.A., & Irwin, D.E. (1995). *Maintaining visual stability across saccades: Role of the saccade target object* (Technical Report No. UIUC-BI-HPP-95-01). Champaign: Beckman Institute, University of Illinois.

Dennett, D.C. (1991). *Consciousness explained.* Boston: Little, Brown and Co.

Enns, J.T., & DiLollo, V. (1997). Object substitution: A new form of masking in unattended visual locations. *Psychological Science 8,* 135–139.

Friedman, A. (1979). Framing pictures: The role of knowledge in automatized encoding and memory for gist. *Journal of Experimental Psychology: General, 108,* 316–355.

Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Perception* (Vancouver Studies in Cognitive Science, Vol. 5, pp. 89–109). New York: Oxford University Press.

Intraub, H. (1981). Rapid conceptual identification of sequentially presented pictures. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 604–610.

Irwin, D.E. (1991). Information integration across saccadic eye movements. *Cognitive Psychology, 23,* 420–456.

Kahneman, D., Treisman, A., & Gibbs, B. (1992). The reviewing of object files: Object specific integration of information. *Cognitive Psychology, 24,* 175–219.

Klein, R., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 46–65). New York: Springer.

Loftus, G.R., & Mackworth, N.H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Human Perception and Performance, 4,* 547–552.

Mack, A., Tang, B., Tuma, R., Kahn, S., & Rock, I. (1992). Perceptual organization and attention. *Cognitive Psychology, 24,* 475–501.

McConkie, G.W., & Zola, D. (1979). Is visual information integrated across successive fixations in reading? *Perception & Psychophysics, 25,* 221–224.

Neisser, U., & Becklen, R. (1975). Selective looking: Attending to visually significant events. *Cognitive Psychology, 7,* 480–494.

Nothdurft, H.C. (1992). Feature analysis and the role of similarity in pre-attentive vision. *Perception & Psychophysics, 52,* 355–375.

O'Regan, J.K. (1992). Solving the "real" mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology, 46,* 461–488.

Pashler, H. (1987). Detecting conjunctions of color and form: Reassessing the serial search hypothesis. *Perception & Psychophysics, 41,* 191–201.

Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics, 44,* 369–378.

Phillips, W.A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics, 16,* 283–290.

Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3–25.

Potter, M.C. (1976). Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory, 2,* 509–522.

Pylyshyn, Z.W., & Storm, R.W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision, 3,* 179–197.

Rock, I., Linnett, C., Grant, P., & Mack, A. (1992). Perception without attention: Results of a new method. *Cognitive Psychology, 24,* 502–534.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74,* 1–29.

Stroud, J.M. (1955). The fine structure of psychological time. In H. Quastler (Ed.), *Information theory in psychology: Problems and methods* (pp. 174–207). Glencoe, IL: Free Press.

Wolfe, J.M. (1996). Post-attentive vision. *Investigative Ophthalmology & Visual Science, 37,* 214.

Wolfe, J.M., Cave, K.R., & Franzel, S.L. (1989). Guided search: An alternative to the feature integration model for visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 419–433.