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# Prioritization of New Objects in Real-World Scenes: Evidence From Eye Movements

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The authors examined the prioritization of abruptly appearing objects in real-world scenes by measuring the eyes' propensity to be directed to the new object. New objects were fixated more often than chance whether they appeared during fixations (transient onsets) or saccades (nontransient onsets). However, onsets that appeared during fixations were fixated sooner and more often than those coincident with saccades. Prioritization of onsets during saccades, but not fixations, were affected by manipulations of memory: Reducing scene viewing time prior to the onset eliminated prioritization, whereas prior study of the scenes increased prioritization. Transient objects draw attention quickly and do not depend on memory, but without a transient signal, new objects are prioritized over several saccades as memory is used to explicitly identify the change. These effects were not modulated by observers' expectations concerning the appearance of new objects, suggesting the prioritization of a transient is automatic and that memory-guided prioritization is implicit.

*Keywords:* scene processing, visual short-term memory, attention capture, eye tracking

When viewing a scene, observers volitionally deploy attention to regions of interest. The guidance of the eyes through a scene is an active process of interrogating scene regions to extract information relevant to one's goals. One of the earliest illustrations of this is Yarbus's (1967) study of eye movements during picture viewing. An observer's purpose in viewing a picture altered the distribution of his or her fixations. For example, when estimating the age of people, the eyes were primarily directed to faces, whereas when assessing the economic status of people, the eyes were directed to their clothing. More recent work has demonstrated that regions of a scene that are subjectively described as informative (Mackworth & Morandi, 1967) or that contain unexpected objects (Henderson, Weeks, & Hollingworth, 1999) receive a disproportionate number of fixations. These results suggest that the eyes are directed to positions that an observer deems to be important to understanding a scene.

Fixation placement is also thought to be, at least in part, influenced by the visual salience associated with objects in a scene. Models linking salience and gaze control argue that for every scene, visual processing areas of the brain construct a saliency map demarcating regions of varying salience. Generally, these models posit that visual saliency is computed as a function of several image properties including color, intensity, orientation (Itti & Koch, 2000; Koch & Ullman, 1985; Parkhurst, Law, & Niebur, 2002), contour junctions, termination of edges, stereo disparity, shading (Koch & Ullman, 1985), and motion (Koch & Ullman, 1985; Rosenholtz, 1999). Visual salience and fixation location tend to be positively correlated, especially early on in viewing, indicating that fixated regions are higher in mean saliency (Parkhurst et al., 2002; but see also Henderson, 2003, and Turano, Geruschat, & Baker, 2003, for discussion of some limitations of stimulus-based models).

In addition to the modeling work on visual saliency that is correlational in nature, some experimental work also suggests a role of saliency in gaze control. The effect of visual salience on attention allocation and gaze control is perhaps most strikingly illustrated when unique or distinctive aspects of a scene grab people's attention even when these aspects are irrelevant to people's goals, a phenomenon known as *attention capture.* Several kinds of stimuli including the abrupt onset of a new object, a unique color or shape, and certain types of motion have been demonstrated to capture attention (e.g., see Chastain, Cheal, & Kuskova, 2002; Franconeri & Simons, 2003; Jonides & Yantis, 1988; Theeuwes, 1994). In terms of gaze control, top-down direction of the eyes can be disrupted by the abrupt appearance of a new but task-irrelevant object, a phenomenon called *oculomotor capture* (Irwin, Colcombe, Kramer, & Hahn, 2000; Theeuwes, Kramer, Hahn, & Irwin, 1998). For example, while searching for a color singleton in a visual display, the eyes were involuntarily drawn to a nontarget onset for a brief time before the eyes moved on to the desired target. This capture of the eyes occurred on approximately 50% of trials. Fixations on the onset were atypically brief, suggesting that the saccade to the target was programmed, but before it could be executed the onset interrupted this goal-

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directed eye movement. What is more, observers were often unaware of this deviation (Theeuwes et al., 1998). Thus, sudden changes can influence the allocation of attention to a visual display by influencing the eyes' scan pattern.

The majority of the evidence for both attention capture and oculomotor capture is based on the interruption of goal-directed behavior when a single unique shape or letter is present in a simple stimulus array (see Belopolsky, Theeuwes, & Kramer, 2005; Donk & Theeuwes, 2003, for exceptions). If the ultimate goal of this work is to infer how objects are prioritized during normal viewing of the world, it is vital that analogous effects be studied in the context of natural scenes. Real-world scenes possess a degree of complexity and semantic coherence far greater than a simple stimulus array. Scenes are dynamic collections of background elements, surfaces and structures, manipulable objects, occlusions, and myriads of textures and colors. In short, scenes do not contain a single unique item among a set of homogeneous objects; all items in a scene are unique in some way. As a result, the extent to which previous demonstrations of attention capture, where a single unique item is present, apply in the real world remains an open question. Here, for the first time, we investigate whether the most robust kind of capture—that associated with the appearance of a new object—occurs during natural scene viewing by asking whether a new object in a scene is visually salient enough to drive attention and the eyes to it.

Why would new objects be visually salient in a real-world scene? One possibility is that attention is driven to low-level scene changes that are associated with the appearance of a new object. For example, a new object is often accompanied by a transient motion signal and abrupt changes to surrounding local image features such as color, intensity, contrast, edge density, and clutter in the region to which it is added. A new object may also disrupt the spatial relationships shared among existing objects and may occlude objects originally present in the scene. Under this view, it is not a new object per se that is identified and prioritized but one or more of these low-level transient changes that is introduced to a scene by an onset. Indeed, recent work has demonstrated that new objects introduced in simple displays of letters and shapes capture attention consistently when observers can see the transient created by the onset but not when the transient is suppressed by introducing the new object during a brief occlusion of the display (Franconeri, Hollingworth, & Simons, 2005). In addition to providing an explanation for capture by onsets, this transient change hypothesis is also able to account for the capture effects observed with luminance increments and motion, each of which introduces low-level statistical changes to the composition of a visual display. Furthermore, transient signals affect other aspects of visual awareness. For example, observers often fail to detect changes in visual displays and real-world scenes such as object displacements, substitutions, or deletions when they occur during a visual disruption that eliminates the transient signals associated with the changes, such as intervening time intervals (e.g., Pashler, 1988; Simons, 1996), masks (e.g., Rensink, O'Regan, & Clark, 1997), sudden viewpoint changes (e.g., Levin & Simons, 1997), or saccades (e.g., Currie, McConkie, Carlson-Radvansky, & Irwin, 2000; Henderson, 1997; Henderson & Hollingworth, 1999b; Irwin, 1991).

Another possibility is that the attention system considers the appearance of a new object to be behaviorally relevant. As a result, new objects are prioritized (e.g., Yantis, 1993, 1996). Empirical evidence for this hypothesis relies on demonstrations that unique stimulus features of existing objects such as luminance increments sometimes fail to capture attention (e.g., Jonides & Yantis, 1988; Todd & Kramer, 1994). The new object hypothesis is, however, limited by demonstrations that uniquely colored objects (e.g., Theeuwes, 1994) or the disappearance of objects (e.g., Chastain et al., 2002) also capture attention under certain circumstances.

A second aim of this article was to contrast the transient change hypothesis and the new object hypothesis in real-world scenes. We addressed the role of a transient signal in the prioritization of new objects by presenting the new item either during a fixation so that it retained its transient status or during a saccade, which because of saccadic suppression eliminated the transient signal. Our second major question, then, was as follows: Given a visual disruption (i.e., a saccade) coincident with the onset of a new object, does the new object still draw attention? If prioritization is driven by the detection of a transient signal in a scene, the answer should be "no." According to the new object hypothesis, however, the answer should be "yes." This manipulation also serves as a behavioral test of saliency models that incorporate transient signals such as motion as a factor in determining visual saliency.

A final goal of this article was to assess whether an observer's expectations about whether new objects would appear in a scene would alter the rate with which onsets are attended. Several researchers have argued that capture depends on similarities between the feature(s) of the search target and the capturing item (Atchley, Kramer, & Hillstrom, 2000; Folk, Remington, & Johnston, 1992) or that such effects depend on the search strategy adopted by participants (Bacon & Egeth, 1994). For example, a unique color captures attention when color features define the target of one's search but not when participants are searching for an onset, an effect called *contingent capture* (e.g., Folk et al., 1992). Furthermore, researchers have suggested that capture by onsets might result from a default attention set for dynamic events (Folk, Remington, & Wright, 1994; Franconeri & Simons, 2003) or from a task-induced attention set for the appearance of a new item (e.g., Gibson & Kelsey, 1998). To investigate whether expectations influence capture in real-world scenes, we gave observers either no instruction concerning the appearance of new objects and we told them to memorize each visual scene for a later memory test or we instructed them to search for and identify new objects introduced to the scene after viewing had begun. The question of interest was whether explicit search for a new object would increase the likelihood that the onset would be prioritized and whether top-down knowledge or expectations would alter the salience of a new object when it appeared in a visual display.

## Experiment 1

Experiment 1 had three main objectives: to determine whether new objects attract attention in natural scenes, to determine whether the presence of a transient signal influences the degree to which such attraction is observed, and to determine whether expectations alter the degree to which a new object will draw attention. The general methodology married the oculomotor capture paradigm and real-world scene viewing. Observers viewed photographs of scenes as their eye position was monitored. The location of eye fixation was taken as an index of the locus of attention within the scene. To test whether the appearance of a new object draws attention in scenes, we added a single new object to each scene during viewing (see Figure 1 for examples). If a new object draws attention, the probability that the new object is fixated should be higher than would be expected had the object always been present (determination of this baseline is discussed below). Furthermore, the eyes should be drawn to the new object very quickly and so the elapsed time between the object's appearance and an observer's first fixation on the object should be very brief. We operationalized this time component as the number of intervening fixations between the appearance of the new object and an observer's first fixation on that object.

To assess the role that a transient signal plays in the attraction of attention to a new object, we added the additional object either during a fixation or during a saccade. A new object that appears during a fixation retains its role as a transient change to the scene, whereas saccadic suppression eliminates the transient signal if the new object appears during a saccade. The analysis of interest, then, is whether the new object is prioritized relative to other objects in the scene in one or both of these situations. If new objects draw attention because they introduce a transient change to the low-level stimulus features present in the scene, then prioritization should only be observed if the new object is presented during a fixation. On the other hand, if the new object itself draws attention, the transient status of the onset should be irrelevant and attention should be devoted to the object in both conditions.

Finally, to determine whether an expected new object draws attention more readily than an unexpected new object, half of the participants were given no instruction pertaining to the appearance of new objects and half of the participants were explicitly told to search for and to identify the new object on every trial. If expectation plays an important role in the allocation of attention to new objects in natural scenes, then stronger prioritization should be observed when observers are aware that new objects will appear and are searching for them.

## Method

*Participants.* Twenty-four Michigan State University undergraduates with normal or corrected-to-normal vision participated after providing informed consent. All participants were naive with respect to the experimental hypotheses and were compensated with course credit.

*Stimuli.* Stimuli consisted of full-color photographs depicting 30 real-world scenes. Two photographs of each scene were taken, differing only in the presence or absence of a single object in the scene (see Figure 1 for examples). Photographs were digitally edited only to ensure that they did not differ in any way other than the presence of the object, such as subtle changes in light and shadow. We also removed any "jitter" that might be perceptible when the photographs were alternated. Each photograph was displayed at a resolution of 600 pixels × 800 pixels × 24-bit color and subtended 37° horizontally and 27.5° vertically at a viewing distance of 57 cm.

*Apparatus.* The stimuli were presented on a 19-in. Dell P991 monitor driven by a NVIDIA GeForce3 video graphics card with a screen refresh rate of 100 Hz. Eye movements were monitored using an ISCAN ETL-400 pupil and corneal reflection tracking system sampling at 240 Hz. The eye tracker was accurate to within .5° of visual angle both horizontally and vertically. Chin and forehead rests were used to maintain the participant's viewing position and distance. The eye tracker and display monitor were interfaced with a 2-GHz Pentium 4 microcomputer. The computer con-

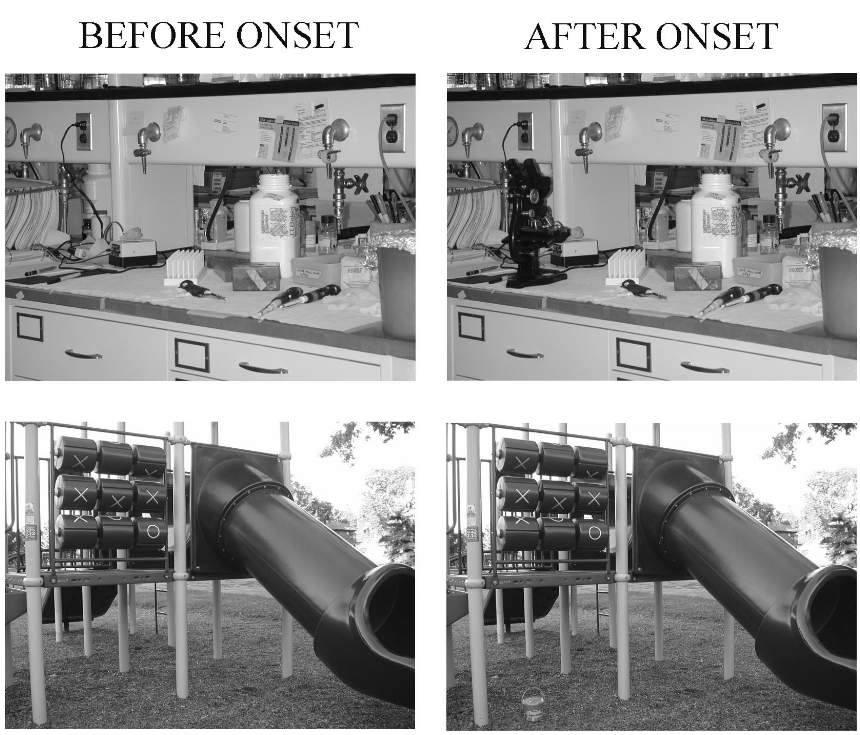


*Figure 1.* An example scene used in this study depicted both before (left panels) and after (right panels) the onset (in these cases, the microscope and bucket).

trolled stimulus presentation and maintained a complete record of eye position throughout the trial.

*Design and procedure.* Participants were randomly divided into three conditions: memorization condition, search condition, and control condition. The memorization and search conditions each included the addition of a new object to a scene during viewing. The control condition (discussed later) did not involve any scene changes. Participants in the memorization condition were instructed to memorize each scene in preparation for a subsequent test in which they would discriminate the studied scenes from scenes in which a detail of a single object would be altered (in actuality, however, this test was never given). Participants in this condition were given no instruction related to the appearance of new objects. In contrast, participants in the search condition were explicitly told that while they were viewing the display a new object would appear. Their task was to search for the new object and, if possible, to identify it at the conclusion of each trial. Aside from the differences in instruction, the trial events were identical in these two conditions.

Participants began the experimental session by completing a calibration routine that served to map the output of the eye tracker onto display position. Calibration was monitored by the experimenter and adjusted when necessary. Participants began each trial by fixating a dot in the center of the display; when they indicated they were ready to view the stimulus, a photograph of a real-world scene was displayed for 10 s. During viewing, a single new object was added to the scene by changing the photograph presented on the display to its associated counterpart that contained the additional object. Phenomenologically, this change looked like the addition of an object to the preexisting scene.

An eye-movement-contingent display change technique was used to trigger the appearance of the new object. The onset was tied to the first time the eyes crossed the midline of the display after 5 s had elapsed since the beginning of the trial. As such, observers viewed each stimulus for at least 5 s before the new object appeared. When the new object was to appear during a saccade, it appeared as soon as the eyes crossed the midline following the 5-s interval. In this condition, the eyes were still moving when the onset appeared. When the onset was to appear during a fixation, it was added 100 ms after the eyes crossed the midline following the 5-s interval. This 100-ms delay was long enough to allow the critical saccade to terminate but short enough that a subsequent saccade could not be launched. In this condition, the onset occurred when the eyes were still. The new object remained in the scene until the conclusion of the trial. Participants in the search condition then identified the new object if they could; no response was required of participants in the memorization condition.

Participants in the control condition studied the same scenes in preparation for a future memory test. No onsets occurred in this condition, however. The object that constituted the onset in the other conditions was visible from the beginning of the trial. This condition enabled a determination of the baseline rate at which the critical object was fixated when it did not constitute an abruptly presented new object.

## Results

In the memorization condition, the new item was added, on average, 6.04 s or 14.6 saccades into viewing when it appeared during a fixation and 5.98 s or 13.7 saccades into viewing when it appeared during a saccade. In the search condition, the new item was added, on average, 5.68 s or 15.6 saccades into viewing when it appeared during a fixation and 6.12 s or 14.1 saccades into viewing when it appeared during a saccade. The new object was successfully onset during a fixation on 94% of fixation onset trials and during a saccade on 83% of the saccade onset trials (remaining trials were excluded from the reported analyses).

Analyses focused on the probability with which a fixation was located on the new object region of the scene. Seven fixations were considered: the three fixations prior to the appearance of the new object (denoted Fixations −3, −2, and −1) and the four fixations following the addition of the new object (denoted Fixations +1, +2, +3, and +4). We refer to this as the *ordinal fixation position*. Fixation +1 denotes the first fixation that could be selected after the new object appeared. Thus, if the new object appeared during a fixation it did so during Fixation −1. If the new object appeared during a saccade, it did so during the eye movement executed between Fixation −2 and Fixation −1. In the latter case, the location of Fixation −1 was selected by the participant prior to the onset because fixation point selection occurs prior to the movement of the eyes.

*The effect of task instruction.* For all analyses, instruction (memorize vs. search), ordinal fixation position (Fixations −3 through +4), and onset condition (fixation vs. saccade) were initially entered into a mixed model analysis of variance (ANOVA). The effect of instruction was not reliable, $F(1, 14) = 1.8$, $p > .20$, nor did it interact with onset condition, $F(1, 14) < 1$, or fixation position, $F(6, 84) = 1.8$, $p > .11$. The three-way interaction among instruction, onset condition, and fixation position was also unreliable, $F(6, 84) < 1$ (see Table 1). Participants who were explicitly instructed to search for suddenly appearing new objects displayed the same general viewing behavior as participants who were not given any instructions regarding new objects. An observer's expectations, therefore, did not substantially alter the probability that a new object was fixated on its

Table 1
*Mean Probabilities and Standard Deviations of Fixating the New Object Broken Down by Instruction Condition, Onset Condition, and Ordinal Fixation Position*

| | Ordinal fixation position | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | −3 | | −2 | | −1 | | +1 | | +2 | | +3 | | +4 | |
| Condition | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Memorize | | | | | | | | | | | | | | |
| Fixation | 5.1 | 6.0 | 3.6 | 3.8 | 10.3 | 4.7 | 56.4 | 13.1 | 62.2 | 24.4 | 46.1 | 20.9 | 35.9 | 19.2 |
| Saccade | 3.4 | 3.6 | 5.1 | 7.0 | 3.3 | 5.0 | 16.4 | 9.6 | 34.5 | 13.1 | 29.6 | 7.4 | 27.6 | 10.0 |
| Search | | | | | | | | | | | | | | |
| Fixation | 3.3 | 7.1 | 1.7 | 4.7 | 3.5 | 3.8 | 59.5 | 21.7 | 72.4 | 12.0 | 58.4 | 13.9 | 46.9 | 18.7 |
| Saccade | 1.0 | 2.5 | 1.7 | 4.7 | 1.6 | 4.4 | 13.3 | 12.4 | 36.8 | 18.1 | 35.7 | 15.5 | 36.9 | 13.6 |

appearance. Remaining analyses therefore collapsed across instruction, and results are derived from a repeated measures ANOVA crossing ordinal fixation position and onset type.

*Probability of fixating new objects.* If a new object draws attention, it should be fixated with higher-than-chance probability. To establish the level of chance, we determined the probability that participants fixated the critical object in the control condition; 10% of fixations were localized on the critical object in the no-onset control condition in this experiment. We refer to this as the *baseline rate of viewing*. As such, one would expect that after the appearance of the new object, the probability of fixating that object should exceed this baseline rate of viewing if it draws attention.

For each scene, a critical region was defined by an imaginary bounding box surrounding the new object. For Fixations −3 through +4, the location of each fixation was sorted according to whether it fell within these critical regions (see Figure 2). Prior to the appearance of the new object, the critical regions generally contained background elements of the scene. During natural scene viewing, however, observers tend to fixate objects rather than the backgrounds (Henderson & Hollingworth, 1998). In the present study, fixations in these regions prior to the appearance of the new item were rare ($M$ = 4%) and did not vary with ordinal fixation position, indicating that the new objects did not appear in regions that were highly salient. In fact, observers fixated the critical region less often prior to the target object's appearance (so that it contained background elements) compared with the baseline rate of viewing for the same critical region when it contained a non-appearing version of the target object (4% vs. 10%). Again, this difference is not surprising given that observers generally prefer to look at scene regions containing objects. These fixations were not analyzed further. The following analyses examined the probability with which the first four fixations following the appearance of the new object were directed to it.

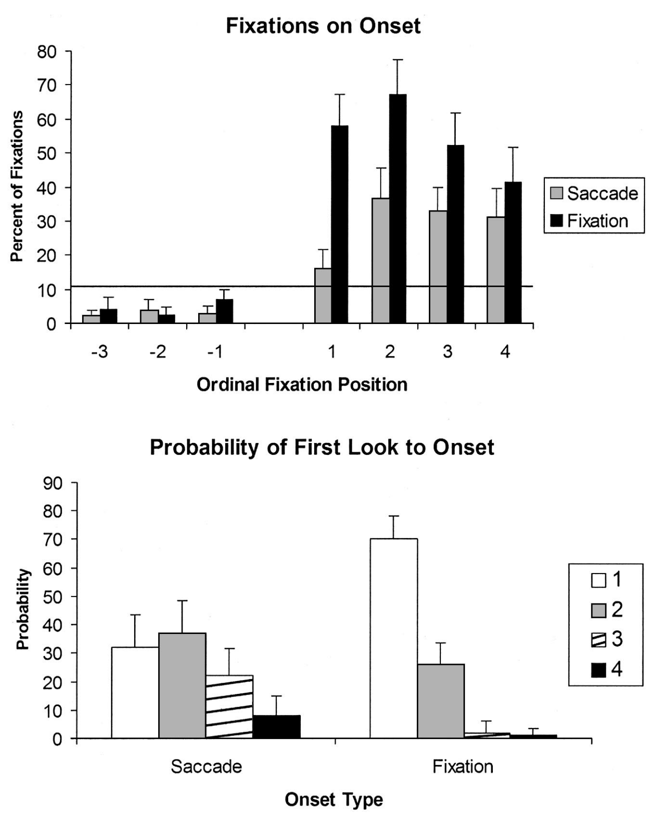


*Figure 2.* Results of Experiment 1. Top panel: The mean probability that fixations just prior to (Fixations −3, −2, −1) and just after (Fixations +1, +2, +3, +4) the onset were localized on the new object. The solid line illustrates the baseline rate of viewing (chance). Bottom panel: The probability of the first look to the new object occurring at each of the first four fixations after its appearance. All error bars represent 95% confidence intervals.

On average, the new object was fixated more often when it appeared during a fixation ($M$ = 55% of first four fixations following onset) compared with when it appeared during a saccade ($M$ = 29% of first four fixations), $F(1, 15) = 65.6$, $MSE = 361.5$, $p < .001$. In the fixation condition, the new object was fixated at least once in the first four fixations after its appearance on 80% of trials. In the saccade condition, the new object was fixated at least once on 47% of trials. Ninety-five percent confidence intervals indicated that for both the saccade and fixation conditions, the new object was fixated more frequently at all ordinal fixation positions relative to baseline rate of viewing except for Fixation +1 in the saccade condition (see Figure 2). A main effect of ordinal fixation position indicated that the new object was not fixated equally at all ordinal fixation positions, however, $F(3, 45) = 15.3$, $MSE = 99.2$, $p < .001$. For both new object types, the new item was fixated most often during Fixation +2 (see Figure 2). Dissimilarities in the effect of ordinal fixation position were also observed between the saccade and fixation conditions, as shown by a reliable interaction of these factors, $F(3, 45) = 15.3$, $MSE = 107.4$, $p < .001$. In the saccade condition, after peaking at Fixation +2, the probability of fixating the new item remained stable. In the fixation condition, however, the probability of fixating the new item decreased markedly between Fixation +2 and Fixation +4.

These results demonstrate that new objects in a scene were fixated with far greater frequency than would be expected by chance in the first few fixations after its appearance, regardless of whether it appeared during a saccade or a fixation. As such, a motion transient was not necessary for a new object to influence gaze. However, a new object accompanied by a transient signal drew the eyes to it twice as often, indicating a prioritizing effect specific to the transient signal.

*Number of fixations to first fixation of new object.* The number of fixations intervening between the onset of the new object and an observer's first fixation on that object is a measure of how quickly the onset is prioritized. On average, the new object was first viewed sooner if it occurred during a fixation ($M$ = 1.6 fixations after onset) than if it appeared during a saccade ($M$ = 3.0 fixations after onset), $t(15) = 6.23$ $p < .001$.

The bottom panel of Figure 2 illustrates the probability that the new item was first fixated at each of the ordinal fixation positions, given that it was fixated at all, broken down by onset condition. Note that in the fixation condition, 94% of all first looks to the new object occurred in the first four fixations after its appearance. In the saccade condition, this rate fell to 84%. The probability that the first look to the new object occurred at each of the first four ordinal fixation positions differed, $F(3, 45) = 73.2$, $MSE = 2.39$, $p < .001$, and these differences were not equal in the saccade and fixation conditions, $F(3, 45) = 33.9$, $MSE = 2.32$, $p < .001$.[1] In the fixation condition, 67% of first looks to the new object occurred at Fixation +1, an observer's first opportunity to do so. This was followed by a rapid decline in the probability of a first look at each of the next ordinal fixation positions. Only 3% of first looks to the new object occurred at Fixations +3 and +4, combined. In contrast, in the saccade condition, 26% of first looks to the new object occurred at Fixation +1. The probability of a first look was just as great at Fixation +2. A moderate decrease followed with 24% of first looks occurring at Fixations +3 and +4, combined. Compared with new objects that appeared during a fixation, prioritization of new objects that appeared during saccades was extended in time. As many first looks to the new object occurred over the course of three fixations in the saccade condition compared with the very first fixation in the fixation condition. In essence, it took longer to prioritize the new object when it was not accompanied by a transient. In conjunction with the prior probability of fixation analysis, we can conclude that a transient signal increased the probability that the new object was prioritized and increased the speed with which the prioritization took place.

*Summary and discussion.* The new object was fixated in the first few fixations after its appearance at rates greater than would be expected had the object not newly appeared, regardless of whether it appeared during a saccade or a fixation. However, a new object accompanied by a transient signal (because it appeared during a fixation) drew the eyes to itself twice as often and was fixated sooner after its appearance compared with a new object not accompanied by a transient signal (because it appeared during a saccade). The differences between the fixation and saccade conditions point to a prioritizing effect specific to the transient signal that often accompanies the appearance of new objects. Specifically, a transient signal markedly increased the probability and speed with which attention was deployed to a new object in a natural scene. This pattern of results matches predictions generated from the attention capture literature that new objects draw attention in real-world scenes. In the saccade condition, however, the majority of fixations on the new object occurred after several fixations, and the observed prioritization effects were less robust. These results suggest that a motion transient is not necessary for a new object to influence gaze. This pattern of results, however, fits less well with a reflexive attention capture interpretation.

Why is prioritization of a new object slower and less reliable when it does not appear as a transient? A possible explanation is that, without a transient signal, new objects are prioritized not by the bottom-up capture of attention but by the top-down deployment of attention that is guided by visual memory. An accurate memory representation of the scene would include where each encoded object is located and which regions are void of objects. When the new object was added, observers could then "realize" that the layout of the scene in the current view did not match the layout stored in the online memory representation. This could lead to the identification, prioritization, and fixation of the discrepant object.

Because visual short-term memory (VSTM) is a limited capacity store (e.g., Irwin & Andrews, 1996; Luck & Vogel, 1997; Pylyshyn & Storm, 1988), the probability of detecting the change would decrease when VSTM is required to guide the prioritization of new objects relative to cases where the new object captures attention. Additionally, because the volitional deployment of attention is slower than the automatic orientation of attention (e.g., Wolfe, Alvarez, & Horowitz, 2000), localization of the new object would be slowed when the new object does not capture attention in a stimulus-driven way. Each of these predicted outcomes is consistent with the results of Experiment 1.

Several research findings already suggest that memory mechanisms may allow visual information to persist across views and thereby guide attention during viewing. First, priming of popout allows image features to direct attention and the eyes on a fixation-by-fixation basis (e.g., Maljkovic & Nakayama, 1994, 1996). The ability of an observer to make a shape discrimination judgment about a uniquely colored item is influenced by the color values associated with unique objects in previous trials. Same colored targets in the recent past can speed discrimination of the current target shape. This suggests that memory for image features can be used to guide attention. This short-term memory (STM) priming is not mediated by explicit conscious processing and is not influenced by prior knowledge. Second, contextual cueing allows the redundancies and regularities of the visual world that people experience to guide attention through visual displays (e.g., Chun & Jiang, 1999). If visual search arrays are repeated in a series of trials, observers gradually become faster at finding the target, despite having no explicit memory for having seen the displays previously. These findings have been extended to natural-scene viewing as repeated exposure to a real-world scene results in faster search times and fewer eye movements to the target object (e.g., Sheinberg & Logothetis, 1998). Finally, if an object change is introduced in a scene to a previously fixated object that is no longer in the focus of attention, the detection of that change can be quite good, but if the critical object had not been attended prior to the change, detection rates are not greater than the false alarm rate, suggesting that information about previously viewed objects and scene regions is amassed in memory as viewing progresses (Henderson & Hollingworth, 1999a; Hollingworth & Henderson, 2000, 2002). Together, these results imply that memory representations contribute to the guidance of attention in visual scenes. It is reasonable to hypothesize, then, that memory for a scene may also guide attention and the eyes to new objects when they appear. Experiments 2 and 3 were designed to explicitly test this memory-based prioritization hypothesis by considering the contributions of STM and long-term memory (LTM), respectively.

## Experiment 2

Experiment 2 addressed whether the prioritization of new objects in the saccade condition of Experiment 1 was guided by VSTM. As viewing progresses, observers build a more complete mental representation of a visual scene that includes identities and details of viewed objects (Castelhano & Henderson, in press; Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2000, 2002; Hollingworth, Williams, & Henderson, 2001; Tatler, Gilchrist, & Rusted, 2003). If prioritization of a new object that appears during a saccade is based on a comparison of the objects

[1] To avoid issues of multicollinearity introduced by expressing the number of first looks to the onset at each ordinal fixation position as a conditional probability, we performed the ANOVAs on the raw number of times the first look occurred at each fixation position.

in the current scene with a memory representation of the objects in that scene, the time at which the onset appears should be critical. Very early in the trial, less information about the scene is encoded into memory than later in the trial. Thus, prioritization based on memory should be stronger and more reliable late in viewing than it would be early in viewing. On the other hand, prioritization based purely on the detection of transient signals should be relatively immune to variations in viewing time. That is, the transient signal should orient attention regardless of an observer's viewing history. To test these predictions, in Experiment 2 we decreased the minimum amount of elapsed time from the start of the trial to the appearance of the new object from 5 s to 30 ms. Because explicit search for onsets did not influence the rate of fixating the new object in Experiment 1, Experiment 2 used a single instruction condition: Participants were asked to memorize the scenes for a later memory test.

## *Method*

*Participants.* Eight Michigan State University undergraduates with normal or corrected-to-normal vision participated in exchange for course credit after providing informed consent. None of the participants had taken part in Experiment 1.

*Stimuli and apparatus.* The same stimuli and apparatus were used as in Experiment 1.

*Design and procedure.* The design and procedure were identical to the memorization condition in Experiment 1 except that the new object appeared when (a) a minimum of only 30 ms elapsed from the start of the trial and (b) the eyes exited an invisible bounding region with a diameter of 2° of visual angle surrounding the center fixation point at the start of the trial.

## *Results*

The new object appeared an average of 459 ms or 1.45 saccades into viewing in the fixation condition and 645 ms or 1.23 saccades into viewing in the saccade condition. Compared with Experiment 1, the time afforded for viewing prior to the onset was reduced by a factor of 11. The new object was successfully onset during a fixation in the fixation condition on 96% of trials and during a saccade in the saccade condition on 82% of the trials (remaining trials were excluded from the reported analyses). Analyses mirrored those in Experiment 1 and are illustrated in Figure 3. Because the new object appeared so quickly into viewing, however, it was only possible to analyze ordinal Fixations −1 through +4. Analyses also compared the results of Experiment 2 with those in Experiment 1 with a mixed model ANOVA.

*Probability of fixating new objects.* Prior to the appearance of the new object, 4% of fixations were directed to regions that would contain the object. On average, the new object was fixated more often if it appeared during a fixation than during a saccade (40% vs. 14%), $F(1, 7) = 22.0$, $MSE = 449.6$, $p < .001$. In the fixation condition, the new object was fixated at least once in the first four fixations after its appearance on 82% of trials. In the saccade condition, the new object was fixated at least once on 30% of trials. The probability with which the new object was fixated varied as a function of ordinal fixation position, as revealed by a main effect of this factor, and were highest at Fixation +2, $F(3, 21) = 5.3$, $MSE = 137.4$, $p < .01$. Ordinal fixation position also interacted with onset type, $F(3, 21) = 10.2$, $MSE = 86.7$, $p < .001$. The probability of fixating the new object remained stable from

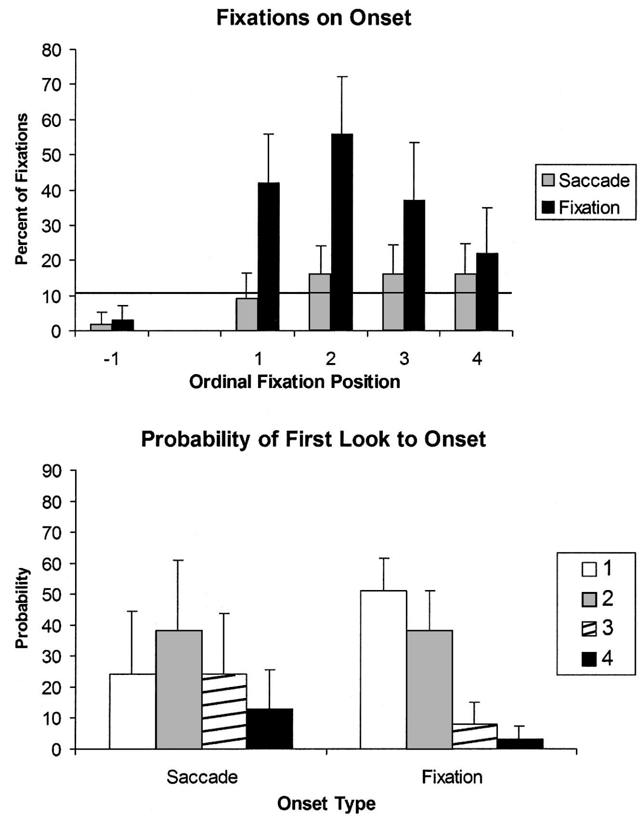


*Figure 3.* Results of Experiment 2. Top panel: The mean probability that fixations just prior to (Fixation −1) and just after (Fixations +1, +2, +3, +4) the onset were localized on the new object. The solid line illustrates the baseline rate of viewing (chance). Bottom panel: The probability that the first look to the new object occurred at each of the first four fixations after its appearance. All error bars represent 95% confidence intervals.

Fixation +2 to Fixation +4 in the saccade condition but decreased in the fixation condition.

Critically, as expected on the basis of the hypothesis that memory supports prioritization of a new object without a transient signal, the probability of fixating the new object in the saccade condition decreased compared with Experiment 1, $F(1, 22) = 9.0$, $MSE = 397.9$, $p < .01$. Strikingly, 95% confidence intervals indicated that this probability did not reliably differ from the baseline rate of viewing (chance) at any ordinal fixation position (see Figure 3). That is, when no transient signal was present and when viewing time was decreased so that the online memory representation of the scene had little time to develop, prioritization of the new object was effectively eliminated.

A reduction in prioritization was also observed in the fixation condition compared with Experiment 1, $F(1, 22) = 5.18$, $MSE = 971.3$, $p < .04$, although the probability of fixating the new object remained well above the baseline rate of viewing. This reduction in orientation to the onset during a fixation from Experiment 1 to Experiment 2 suggests that memory also contributes to the prioritization of transient objects, although this effect is in addition to that elicited by the transient motion signal.

*Number of fixations to first fixation of new object.* In the saccade condition, on average, the new object was fixated 6.3

fixations after its appearance (cf. 3.0 fixations in Experiment 1). Only 50% of first looks to the new object in the saccade condition occurred in the first four fixations after onset (cf. 84% in Experiment 1). No systematic variation in first looks to the new object as a function of ordinal fixation position was observed, $F(3, 21) = 1.3$, $MSE = 1.38$, $p < .31$. Because the new object was not fixated at a rate greater than chance in the saccade condition, the observer's first look to the new object was randomly distributed among each of the four tested ordinal fixation positions.

In the fixation condition, the new object was fixated, on average, 3.0 fixations (cf. 1.6 fixations in Experiment 1) after its appearance, and 86% of first looks to the new object occurred within the first four fixations (cf. 94% in Experiment 1). No reliable differences were observed between the results of Experiment 2 and Experiment 1, $F(1, 21) < 1$. The majority of first looks to the onset occurred at Fixation +1, followed by a rapid decline in the probability that a first look occurred at later ordinal fixation positions.

*Summary and discussion.* Reducing the viewing time prior to the appearance of the new object reduced the amount of prioritization afforded to that object. This reduction was most dramatic in the saccade condition where prioritization was effectively eliminated. This outcome supports the hypothesis that new objects not accompanied by a transient signal are prioritized by matching the current view of the scene to an existing memory representation. In this account, prioritization occurs when the perceptual input and the memory representation differ.

Given recent evidence that LTM for scenes improves performance in tasks such as visual search and change detection (e.g., Hollingworth, 2004), the memory-guided prioritization hypothesis predicts that LTM for a scene should also be able to guide the prioritization of nontransient new objects when STM is unavailable to do so. We investigated the contribution of LTM to attentional prioritization in Experiment 3.

## Experiment 3

Experiment 3 tested whether LTM can direct memory-guided prioritization of new objects in real-world scenes. Participants initially studied all the scenes, with the to-be-added objects removed, under the expectation that they would have to discriminate those scenes from novel, unstudied scenes at a later test. After viewing all the scenes, participants participated in a direct replication of Experiment 2 under the guise that they were being afforded one more opportunity to view all the scenes before their memory test. In this experiment, then, the online representation would be of equal quality to that in Experiment 2, which could not be used to prioritize nontransient new objects. The critical difference, however, was that participants now had LTM for each scene. If LTM is also capable of driving the prioritization of new objects, then prioritization effects in the saccade condition should be observed as they were in Experiment 1. If, however, LTM cannot serve as the basis on which to prioritize new objects, then prioritization effects in the saccade condition should resemble those observed in the saccade condition in Experiment 2.

### Method

*Participants.* Ten Michigan State University undergraduates with normal or corrected-to-normal vision participated in exchange for course credit after providing informed consent. None of the participants participated in Experiments 1 or 2.

*Stimuli and apparatus.* The same stimuli and apparatus were used as in Experiment 1.

*Design and procedure.* The experiment was divided into two phases. First, participants viewed all 30 photographs, with the to-be-onset items absent, for 15 s each. They were instructed to memorize the scenes for a later memory test. Then, they participated in a direct replication of Experiment 2 under the guise that they were being given one more opportunity to study all the scenes before the memory test began. In reality, no test was given.

### Results

The new item was added to the scenes, on average, 567 ms or 2.36 saccades into viewing in the fixation condition and 371 ms or 1.34 saccades into viewing in the saccade condition. The new object was successfully onset during a fixation on 95% of trials and during a saccade on 85% of the trials (remaining trials were excluded from the reported analyses). Analyses mirrored those in Experiment 2 and are illustrated in Figure 4.

*Probability of fixating new object.* Prior to the appearance of the new object, fixations were directed to regions that would contain the object only 5% of the time. In the fixation condition,

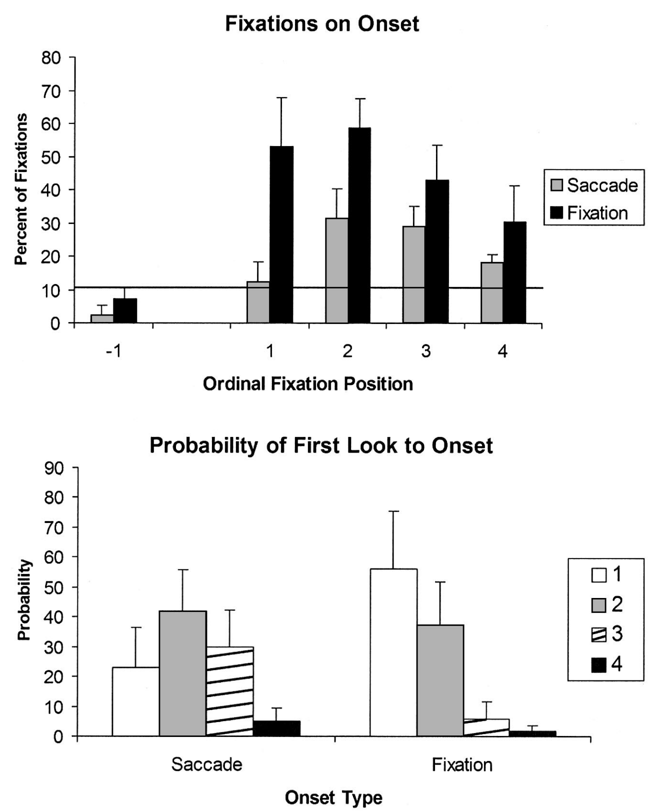


*Figure 4.* Results of Experiment 3. Top panel: The mean probability that fixations just prior to (Fixation −1) and just after (Fixations +1, +2, +3, +4) the onset were localized on the new object. The solid line illustrates the baseline rate of viewing (chance). Bottom panel: The probability that the first look to the new object occurred at each of the first four fixations after its appearance. All error bars represent 95% confidence intervals.

the new object was fixated at least once in the first four fixations after its appearance on 75% of trials. In the saccade condition, the new object was fixated at least once on 50% of trials. On average, the new object was fixated on 46% of the first four fixations when it appeared during a fixation compared with 23% of the first four fixations when it appeared during a saccade, $F(1, 9) = 34.9$, $MSE = 313.8$, $p < .001$. The new object was not fixated equally at all ordinal fixation positions, however, $F(3, 27) = 16.3$, $MSE = 90.2$, $p < .001$. For both onset types, the new object was fixated most often during Fixation +2. Dissimilarities in the effect of ordinal fixation position were also observed between the saccade and fixation conditions, $F(3, 27) = 6.70$, $MSE = 130.4$, $p < .01$, for the interaction of ordinal fixation position and onset condition.

Critically, consistent with the hypothesis that LTM can be used to guide attentional prioritization of nontransient new objects, reliable differences were observed between the saccade conditions in Experiments 2 and 3, $F(1, 16) = 14.2$, $MSE = 87.3$, $p < .01$. Although in Experiment 3 the probability of fixating the new object at Fixation +1 was not different from the baseline rate of viewing, later fixations were directed to the new object at rates greater than the baseline rate of viewing. At Fixation +2, the new object was fixated three times more often than the baseline rate of viewing. Recall that in Experiment 2, fixation of the new object in the saccade condition was at baseline for all ordinal fixation positions.

On the other hand, for the fixation conditions, no reliable differences were observed between Experiments 2 and 3, $F(1, 16) = 1.16$, $MSE = 730.3$, $p < .30$. In the fixation condition, the probability of fixating the new item was always higher than the baseline rate of viewing. The critical result here is that, as opposed to Experiment 2, nontransient new objects in the saccade condition were prioritized. This result supports the hypothesis that LTM can be used to identify changes to a scene (in this case a new object) when, all else being equal, there is insufficient time to construct an online STM representation.

*Number of fixations to first fixation of new object.* In the saccade condition, on average, the new object was fixated 4.1 fixations after its appearance (cf. 6.3 fixations in Experiment 2). Approximately 74% of first looks to the new object occurred in the first four fixations after onset (cf. 50% in Experiment 2). With respect to the fixation condition, the new object was fixated, on average, 2.1 fixations (cf. 3.0 fixations in Experiment 2) after its appearance, and 90% of first looks to the new object occurred within the first four fixations (cf. 86% in Experiment 2).

A reliable main effect of ordinal fixation position demonstrated differences in the rates of first looks to the new object at each ordinal fixation position, $F(3, 27) = 25.9$, $MSE = 3.40$, $p < .001$. A reliable interaction term indicated that these differences were not equal in the saccade and fixation conditions, $F(3, 27) = 13.4$, $MSE = 3.01$, $p < .001$. In the fixation condition, 56% of first looks to the onset occurred at Fixation +1, an observer's first opportunity to do so. This was followed by a rapid decline in the probability of a first look at each of the next ordinal fixation positions. Only 7% of first looks to the onset occurred at Fixations +3 and +4, combined. In contrast, in the saccade condition, 23% of first looks to the new object occurred at Fixation +1. The probability of a first look was reliably higher at Fixation +2, averaging 42%. A moderate decrease followed, with 34% of first looks occurring at Fixations +3 and +4, combined. Compared with onsets during a fixation, prioritization of new objects during saccades was extended in time. Over four times as many first looks to the new object occurred at Fixations +3 and +4 in the saccade condition compared with the fixation condition.

*Summary and discussion.* The above results indicate that LTM for real-world scenes can be used to attentionally prioritize new objects in those scenes even when an online STM representation of the scene is not available. As in Experiment 1, the probability of fixating the new object was above the baseline rate of viewing in both the fixation and saccade conditions, though attention was directed to the new object twice as often in the fixation condition. Likewise, the new object was first fixated sooner if it appeared during a fixation than if it appeared during a saccade: The first look to the new object in the fixation condition was immediate, whereas the first look in the saccade condition was distributed over several fixations. This pattern of results is identical to that observed in Experiment 1 when participants had no prior experience with the scenes and were only able to use an STM representation generated over the course of 6 s against which to compare and guide the eyes to the new object in the saccade condition.

## General Discussion

A unique item in an otherwise homogeneous visual display tends to capture an observer's attention and disrupt the top-down control of gaze (Chastain et al., 2002; Franconeri & Simons, 2003; Irwin et al., 2000; Jonides & Yantis, 1988; Theeuwes, 1994; Theeuwes et al., 1998). One of the most robust capture effects is the disruption of goal-directed behavior by the abrupt appearance of a new but task-irrelevant object (e.g., Jonides & Yantis, 1988). For example, the eyes are often drawn to a new object even when it is known to observers that it does not constitute the target of a visual search (Irwin et al., 2000; Theeuwes et al., 1998). Whether attention deployment and gaze control can be influenced by the appearance of a new object has never been investigated during the normal viewing of real-world scenes. Given that the overarching goal of the attention capture literature is to describe how objects are prioritized during normal viewing of the world, the paradigms often used to study capture in simple displays must be applied to real-world scene viewing. Phenomenological examples suggest that new objects in real-world scenes do draw our attention; stray baseballs and swerving cars that suddenly appear in our visual field seemingly pull our attention toward them so that we can avoid injury. In three experiments, we empirically tested whether objects that abruptly appear in a scene draw attention and what mechanisms underlie this allocation of attention.

In Experiment 1, the new object was added to the scene after approximately 6 s of viewing. When the object appeared during a fixation, over half of the next four fixations were directed to it, a rate consistent with that observed in other oculomotor capture studies that used simple stimulus arrays (e.g., Theeuwes et al., 1998). Approximately two thirds of all first looks to the new object occurred with the fixation immediately following the onset. These results show that a new object attracts attention and gaze quickly and reliably in a natural scene. This result demonstrates the ecological validity of prior onset capture studies. The eyes were also directed to a nontransient new object that appeared during a saccade more often than expected by chance. This result demonstrates that a motion transient is not necessary for the appearance of a new object in a scene to influence gaze. However, a new object accompanied by a transient signal drew the eyes to it twice as often and after half as many fixations as a new object unaccompanied by a transient signal, indicating a prioritizing effect specific to the transient signal. This result suggests that prioritization of the new object in these cases was due to a less efficient, slower, top-down orientation of attention, rather than the automatic capture of attention observed with transient onsets. We hypothesized that an online STM representation of the scene, built over 6 s of viewing, enabled detection and localization of a change to the scene when the change was not accompanied by a transient signal.

To test the memory-guided prioritization hypothesis, in Experiment 2 we reduced the viewing time prior to the appearance of the new object to approximately 550 ms, which afforded participants less time to generate a short-term representation of the scene compared with Experiment 1. The major result of this manipulation was the effective elimination of prioritization of the new object if it was not accompanied by a transient signal. Observers did not fixate the new object after its appearance more often than was expected by chance. Transient onsets, however, continued to draw attention quickly and reliably. This result suggests that both visual and memory mechanisms are involved in the prioritization of objects in real-world scenes. When a transient signal is not available to draw attention, new objects are prioritized if memory is available to guide gaze.

Experiment 3 varied participants' experiences with each scene by enabling them to generate LTMs for each scene. Thus, the contribution of LTM to the prioritization of new objects in real-world scenes was tested. Observers studied each scene for 15 s. They were then shown the scenes a second time during which a new object was presented 550 ms into viewing. In contrast to Experiment 2, where the time that elapsed between the start of scene viewing and the appearance of the onset was the same as in Experiment 3, prioritization of the new object was observed regardless of whether it appeared during a fixation or a saccade, although once again the new object drew attention less frequently and over a longer time course if it was not accompanied by a transient signal. The results showed that even when sufficient time is not afforded to generate an STM representation capable of guiding attention to the new object, observers can rely on their LTM to guide attention through the scene and localize changes.

Finally, no effect of instruction was observed in either the fixation or saccade conditions when it was tested in Experiment 1. The explicit knowledge that new objects would appear did not alter the probability or speed of fixating the object in either the fixation or saccade conditions. This finding suggests that the allocation of attention to transient onsets may be automatic and that memory-guided prioritization is implicit.

Four general conclusions about the prioritization of new objects in real-world scenes can be drawn from these experiments. First, onsets can draw attention in natural scenes. This is an important step in demonstrating the ecological validity of the existing attention capture literature. Second, observers who expect to see a new object are not more likely to prioritize the onset than observers who do not expect new objects to appear. This finding suggests that attention capture by onsets in real-world scenes is automatic, although more work will be required to completely support this conclusion. Third, a strong "new object" theory of attention capture, at least as it applies to the prioritization of a new object in real-world scenes, appears to be false. A reflexive, stimulus-driven capture of the eyes per se did not occur without a transient signal. However, prioritization of nontransient new objects is possible if memory for the scene is available. Thus, new objects themselves can draw attention under certain circumstances. Finally, this memory-guided prioritization can be supported by both an online STM representation created as scene viewing progresses or an existing LTM representation of the scene generated from prior visual experience.

Before concluding, we note that the present study also has implications for other aspects of visual cognition. First, one can draw a direct link between the current results and change blindness or the tendency for an observer to fail to notice changes introduced to a real-world scene such as color changes, object deletions, and object token substitutions from one view of a scene to the next. In essence, attention capture by a new object is a measure of how well a change to a scene is detected. Viewed in this light, not surprisingly, the presence of a transient signal increased an observer's ability to detect a change to a real-world scene. However, change blindness is often observed in experimental paradigms where visual disruptions occur as the change is introduced. In the seminal article on the topic, Grimes (1996) demonstrated that visual disruptions caused by eye movements render an observer blind to changes that occur while the eyes are in saccadic flight. As in the current experiments, Grimes's participants studied photographs of real-world scenes in preparation for a later memory test. While the eyes were moving, details of the scene were changed but unnoticed by observers, even when they were quite substantial, such as two people exchanging heads (see Simons, 2000, for reviews of change blindness). Results of this kind have led some researchers to propose that visual representations of scenes are limited to the currently attended object and that information from past views of a scene is not maintained in memory (e.g., O'Regan, 1992; Wolfe, 1999).

The measures associated with gaze studied in this article, however, lend support to an alternative view of the role that visual memory plays in scene processing. The memory-guided prioritization of nontransient new objects indicates that change detection in the absence of transient signals may be quite good, given sufficient time to construct an STM representation of a scene. In direct contrast with memoryless visual exploration, this result is consistent with the supposition that visual information about a scene accumulates in memory as scene viewing progresses (see Castelhano & Henderson, in press; Hollingworth & Henderson, 2000, 2002, 2004; Tatler et al., 2003). Under this view, the function of attention is to consolidate a high-level representation of an object into a stable memory store. As new objects are fixated, more information about the scene is added to this memory store, leading to a progressively more complete global representation of the scene. This account of visual memory predicts that memory should play a more significant role in gaze control and attention allocation as viewing progresses, a result observed in the present experiments.

We hypothesized that memory-guided prioritization is accomplished by comparing the scene currently before the observer with a stored memory representation derived from prior discrete views (fixations) within that scene. If this view-to-memory comparison can drive gaze, then memory should be available to guide attention in other visual tasks, such as visual search. Recently, however, on the basis of response time measures, some researchers have argued that visual search is memoryless in that observers do not retain information about previously searched items (e.g., Horowitz & Wolfe, 1998). In contrast, research that has measured eye movements during search has found that people have near-perfect memory for which items they have already examined, spanning at least the previous four examined items (e.g., McCarley, Wang, Kramer, Irwin, & Peterson, 2003; Peterson, Kramer, Wang, Irwin, & McCarley, 2001). Direct measures of LTM following visual search have also shown very good memory for the visual details of previously fixated search items (Castelhano & Henderson, in press; Williams, Henderson, & Zacks, in press). Combined with the contrast between our results and previous demonstrations of change blindness, visual memory can be characterized in very different ways depending on the methodologies used, with eye movement measures revealing a much richer role of memory in visual tasks. The use of gaze measures during tasks traditionally investigated using reaction time or accuracy measures may constitute an important step in attaining a more complete understanding of the processes underlying a variety of visual cognitive tasks.

In conclusion, attention is drawn to new objects in real-world scenes. Without an accompanying transient signal, however, new objects are only prioritized if sufficient time has been afforded to create accurate memory for the prechange scene. This study adds to the growing number of demonstrations that both VSTM and LTM for scenes can be used to efficiently guide gaze to identify and prioritize important aspects of the world. For example, STM for the stimulus features associated with prior search targets influences the rate at which future targets are identified that share similar or dissimilar features (Maljkovic & Nakayama, 1994, 1996). Additionally LTM for the layout of a visual display reduces the time (Chun & Jiang, 1999) and eye movements needed to find a search target (see Cohen, Poldrack, & Eichenbaum, 1997). In the present study, new objects could be prioritized if either an STM or LTM representation of the scene was available. These representations required time to generate, indicating that rapid scene identification or extraction of gist was not a sufficient representation for the detection of new objects. Finally, the use of memory to prioritize new objects when they did not capture attention supports the view that attention is used to consolidate visual information into a stable memory format that can be used to guide online scene processing (Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2000, 2002; Hollingworth et al., 2001).

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