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Saccade Latency Reveals Episodic Representation of Object Color

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Abstract

While previous studies suggest that identity, but not color, plays a role in episodic object representation, such studies have typically used tasks in which only identity is relevant, raising the possibility that the results reflect task demands rather than the general principles that underlie object representation. In the present study, participants viewed a preview display containing one (Experiments 1 and 2) or two (Experiment 3) letters, then viewed a target display containing a single letter, in either the same or a different location. Participants executed an immediate saccade to fixate the target; saccade latency served as the dependent variable. In all experiments, saccade latencies were longer to fixate a target appearing in its previewed location, consistent with a bias to attend to new objects rather than to objects for which episodic representations are being maintained in visual working memory. The results of Experiment 3 further demonstrate, however, that changing target color eliminates these latency differences. The results suggest that color and identity are part of episodic representation even when not task relevant, and that examining biases in saccade execution may be a useful approach to studying episodic representation.

Fundamental to visual cognition is the formation of representations of visual information following visual inspection of a scene. Such representations may focus on global scene properties, such as the scene's gist (e.g., Potter, 1976) or layout (e.g., Sanocki, 2003). In addition to these global scene properties, however, observers also form representations of the objects present within the scene (e.g., Hollingworth, 2006). The present study is focused on representations of specific object exemplars that are present in a particular location and time, often referred to as *token* (Henderson, 1994) or *episodic* representations. Such representations are thought to reside within visual working memory (e.g., Gajewski & Brockmole, 2006), and play an important role in many aspects of visual cognition.

Episodic representations appear to play a critical role in maintaining perceptual stability across change, while viewing a dynamic display (e.g., Kahneman, Treisman, & Gibbs, 1992) or while moving one's eyes within a scene (e.g., Irwin, 1996; Henderson & Seifert, 2001). Irwin and his colleagues (e.g., Irwin, 1996; Irwin & Andrews, 1996), for example, have argued that transsaccadic integration, which underlies the perception of stability across eye movements, is supported primarily by a limited set of episodic representations that are maintained across the saccade. Similarly, Kahneman and Treisman (1984) argue that

episodic representations support integration of object information within dynamic displays, when the information that can be derived from a particular object is constantly changing. Finally, episodic representations of objects may form the foundation for constructing representations of more complex scenes (e.g., Hollingworth, 2004), and so understanding such representations is fundamental to an understanding of visual representation in general. Among the most successful theories of object representation is the *object file theory* proposed by Kahneman and Treisman (1984), in which each attended object is represented by a “file” that integrates and maintains information about the object over time.

Episodic representations are thought to play a critical role in supporting perceptual continuity across change. According to object file theory, continuity depends on the outcome of a series of processing stages. When an object is first attended, an object file is constructed to represent that object. When a change occurs – whether because of a change within the scene or because of an eye movement – a correspondence process establishes links between the objects that are visible and the object files that are stored in memory. Early evidence suggested that this correspondence is made primarily, or exclusively, on the basis of spatiotemporal display properties (e.g., Kahneman, Treisman, & Gibbs, 1992; Mitroff & Alvarez, 2007). More recent evidence, however, suggests that other object properties, such as color, may be used to establish correspondence as well (e.g., Richard et al, 2008; Tas, Dodd, & Hollingworth, 2012). Once the correspondence has been established, a reviewing process is engaged, in which object files are retrieved from memory and a comparison is made between the currently visible objects and their object file representations. When there is a match, continuity is preserved. In the absence of a match, however, it is necessary to construct a new object file to represent the object; in this case, continuity is disrupted, and responses to the new object are slowed.

Evidence in support of object file theory has generally come from studies using a *reviewing paradigm* developed by Kahneman, Treisman, and Gibbs (1992). In the typical version of this paradigm, participants begin each experimental trial by viewing two objects (in many cases, square frames or boxes) that are located at an equal distance from a fixation point. A *preview* display is presented that contains two stimuli (typically letters or pictures), one within each box. A short time later, the letters or pictures disappear, leaving only the boxes visible. Following a *linking* display during which the boxes either move to new locations or stay within their previewed locations, a *target* display is presented; the target display contains a single letter or picture within one of the boxes, and the participant’s task is to name the target (e.g., Gordon & Irwin, 1996, 2000; Henderson, 1994; Kahneman, Treisman, & Gibbs, 1992) or indicate whether or not it matches one of the stimuli from the preview display (e.g., Mitroff, Arita, & Fleck, 2009; Noles, Scholl, & Mitroff, 2005).

Kahneman, Treisman, and Gibbs (1992) included three experimental conditions, and used these to assess two types of preview benefit that were of theoretical interest. In the same-object condition, the target matched the stimulus that was presented within the same box in the preview display. In the different-object condition, it matched the stimulus presented within the other box in the preview display. Finally, in the no-match condition, the target did not match either of the two preview stimuli.

By comparing reaction times (RTs) within these three conditions, Kahneman, Treisman, and Gibbs (1992) were able to identify two sources of preview benefit in participants' responses. First, they measured a general benefit of having previewed the target item before having to identify it; they termed this the non-specific preview benefit, and it was calculated as the difference in RT between the different-object and no-match conditions. Of greater interest was the object-specific preview benefit, which was calculated as the difference in RT between the same- and different-object conditions. In both cases, identification of the target benefitted from having seen a preview of the object in the first display. The proposed reviewing process, however, would indicate a match in the same-object condition, but not in the different-object condition, between the target object and its object file representation. The object-specific preview benefit is therefore a measure of perceptual continuity: the presence of the benefit suggests that continuity was preserved in the same-object condition, but disrupted in the different-object condition. In a series of experiments, Kahneman, Treisman, and Gibbs reported a significant object-specific preview benefit whenever the correspondence process was able to establish a link between the preview and target displays.

Considerable work has been done since the theory was first published, seeking to understand the features that are represented in object files and that play a role in supporting perceptual continuity across change (e.g., Gordon & Irwin, 1996, 2000; Gordon & Vollmer, 2010; Gordon, Vollmer, & Frankl, 2008; Henderson, 1994). The general approach that has been used involves manipulating the features that are shared between the preview and target items, and determining which features can be changed without disrupting perceptual continuity (as measured by the object-specific preview benefit). Henderson (1994), for example, found that changing the case in which a letter was presented (e.g., previewing an uppercase 'A' with a lowercase 'a') did not disrupt object continuity. Similarly, Gordon and Irwin (1996) found that previewing object pictures with object labels did not disrupt continuity. Furthermore, using a transsaccadic version of the reviewing paradigm developed by Henderson and colleagues (e.g., Henderson & Seifert, 2001), Gordon, Vollmer, and Frankl (2008) found that object orientation could change without disrupting continuity. Using the same paradigm, Gordon and Vollmer reported that changing stimulus color did not reduce the object-specific preview benefit when the stimuli were letters, or when the target was an object (e.g., a car) that does not have a single typical or diagnostic color. For objects that do have a diagnostic or typical color, however, such as a banana, color mismatches between the preview and target presentations were sufficient to disrupt perceptual continuity and reduce the object-specific preview benefit. Gordon and Vollmer concluded that object color plays a role in preserving perceptual continuity only when it is critical to the object's identity.

Based on these and similar studies using the reviewing paradigm, it has been argued that object continuity depends most critically on abstract object properties, such as identity, rather than on the physical properties of the object. Indeed, identity seems to have a special status: changing an object's identity always disrupts its continuity, and changing other object properties disrupts continuity only to the extent that it affects the object's identity.

While robust across the object file literature – particularly in studies using the classic reviewing paradigm – the results suggesting a limited representation or use of color

information is at odds with a number of studies demonstrating episodic representations of color (e.g., Johnson, Hollingworth, & Luck, 2008; Tas, Dodd, & Hollingworth, 2012) and their use in the operations that preserve object continuity (e.g., Richard et al, 2008). These conflicting results may reflect the fact that studies using the reviewing paradigm (that have suggested a critical role for identity, but not color) have most often used as the primary task identification of the target object. That is, in each of these experiments, identity was relevant to the participants' primary task, but features such as letter case, color, orientation, and form were not. This may have profound consequences for the features that become part of the object file representation, or that play a role in the comparison process that is at the heart of object file reviewing and continuity. Schreij and Olivers (2013), for example, had participants perform a visual search task in which search displays and target locations could be repeated from one trial to the next. After each search display was repeated, it seemed to disappear behind a nearby wall. It then either re-emerged from behind the same wall (such that it appeared to be the same "object" as on the previous trial) or it emerged from behind a different wall (and therefore appeared to be a different object). Schreij and Olivers found (consistent with earlier work by Schreij and Olivers, 2009) that there was an advantage to repeating target location within the display on subsequent trials, and that this was especially pronounced for trials in which the display appeared to be the same object on each trial.

Critically, Schreij and Olivers (2013) also manipulated the consistency of task-irrelevant features within the display (for example, the presence of a salient distractor within the display). While task-relevant features (e.g., target location) appeared to be bound to the representation of the display object, task-irrelevant features were not. In other words, the nature of the representation was at least partly determined by the demands of the primary task. If this is the case in the classic reviewing paradigm, which requires target identification as its primary task, it would suggest that changes to an object's surface properties fail to disrupt continuity, not because those properties are inherently less important for preserving continuity, but simply because they are irrelevant to the task at hand.

This concern exposes a fundamental problem with the reviewing paradigm, which requires that some object feature be made task-relevant, and may therefore privilege some features over others in the representation and utilization of episodic information. The study of episodic representation (in particular, to address the issue of which object features are represented) would benefit from the application of new methodology that equates the task-relevance of an object's features. The approach taken in the present investigation is to examine the effects of episodic object representation on eye movement control. Specifically, participants are shown a preview display containing one or two colored letters; after a linking display, a target display is presented that contains a single colored letter to which participants must make a saccade. At issue is the time taken to initiate the saccade when the target either matches or fails to match the preview letter that was presented at the same spatial location.

Although relatively little work has been done that directly examines control of saccades under such conditions, there are a large number of studies examining attentional biases that are potentially relevant in making predictions from the application of this new approach (e.g., Soto et al, 2005; Yantis & Hillstrom, 1994). Because there is a close correspondence

between spatial attention and eye movements (e.g., Irwin & Gordon, 1998), it is assumed in the present study that factors that influence shifts of attention may, as a result, influence saccade latency. Therefore, on the basis of previous work examining attentional biases, two competing hypotheses were developed and tested in the present study. The first (the *VWM Guidance* hypothesis) predicts that the eyes will be guided more quickly to stimuli that match the contents of visual working memory; the second (the *New Object* hypothesis) predicts faster saccades to stimuli that do not match visual working memory contents. Previous work supporting each hypothesis is described below.

In support of the VWM Guidance hypothesis, a growing body of evidence suggests that attention may be guided by the contents of visual working memory, such that attention is biased to select stimuli that match items in memory (e.g., Cosman & Vecera, 2011; Downing, 2000; Soto et al, 2005). Such findings concerning biases in spatial attention have particular relevance in the present study, given that episodic object representations are thought to reside within visual working memory (Gajewski & Brockmole, 2006), and are explicitly tied to spatial locations (e.g., Kahneman, Treisman, & Gibbs, 1992),

Soto et al (2005), for example, had participants perform a visual search task in which the target was a tilted line and the distractors were vertical lines. Each item in the search display was contained within a colored shape (for example, the target might appear within a red circle, while distractors might appear within a blue hexagon, a green rectangle, and a blue rectangle. The color and form of the shapes surrounding the lines were irrelevant to the task and to the required response.

Prior to the onset of the search display, participants were shown a display containing a memory item, a colored shape that they had to remember for a subsequent memory test. On valid trials, the target in the subsequent search display was presented within a colored shape that matched the memory item; on invalid trials, one of the distractors appeared within the memory shape during the search task. Compared with a neutral condition (in which memory item did not appear within the search display), participants found the target more quickly when it appeared within the memory item, but found it more slowly when the memory item surrounded one of the distractors instead. Soto et al (2005) concluded that there is an involuntary top-down bias to attend to items that match the content or working memory; this facilitates search when the target appears within the item but impairs search when a distractor appears within the item. Soto et al (2005) showed further that this attentional guidance is effective very quickly following the onset of the search display, affecting even the very first saccade made during search.

Though effects of visual working memory representation on attention have typically been shown within the context of a visual search task, it is possible that the top-down bias these studies reveal may contribute to performance in any situation requiring spatial attention. The current task, which requires participants to execute a saccade to a target location, may therefore provide an opportunity for top-down attention biases to be expressed. Specifically, saccade latency should, on this account, be shorter when the target matches the preview stimulus in the same location than when it matches the stimulus in the other location.

Support for the New Object hypothesis comes from previous work demonstrating that the appearance of a new perceptual object is sufficient to capture attention (e.g., Oonk & Abrams, 1998; Yantis & Hillstrom, 1994). According to object file theory, a mismatch between an object's appearance and its episodic representation should necessitate the creation of a new representation, signaling the appearance of a new perceptual object (Kahneman & Treisman, 1984). When the target fails to match its representation in the present experiment, therefore, this mismatch may facilitate faster saccades.

Yantis and Hillstrom (1994) provide evidence for an attentional bias to select new perceptual objects following the creation of a new episodic representation. Participants performed a search task in which a variable number of items appeared on the screen; participants had to indicate whether an H or a U was present in the display. Prior to the search display, a preview display was presented that contained Figure Eights at all but one of the locations in the search display. Thus, one item (the new item) in the search display appeared at a previously unoccupied display location, while the other items appeared at locations that had previously contained Figure Eights. Yantis and Hillstrom were careful to control the luminance of the background and of the items in both displays, so that there were no luminance changes at any location across the display (instead, items were defined by texture, motion, or depth).

The target H or U could appear as a new item in the search display, or could appear in a previously occupied location, and Yantis and Hillstrom (1994) examined the effect of display size in each condition. The results indicated that, when the target appeared in a previously occupied location, the time taken to identify the target increased as display size increased. In contrast, when the target was a new item within the display, the time taken to identify it was unaffected by increases in display size. The authors concluded that the appearance of a new object in the search display captured attention, even when it was not accompanied by a luminance change. The results thus provided support for the authors' argument that events that trigger the creation of a new object file will lead to attention capture. Further support was provided by Hillstrom and Yantis (1994), who found that motion captures attention only when it leads to object file creation. These results therefore provide support for the New Object hypothesis, and suggest that saccade latencies in the present experiments may be shorter for targets appearing in a new location than for targets appearing in their previewed location.

In summary, the results of previous work therefore suggest two possible effects of perceptual continuity on saccade guidance: attention (and the eyes) may be biased to select objects that match episodic representations stored in working memory (VWM Guidance hypothesis), or may be biased to select new perceptual objects whose appearance triggers the creation of a new episodic representation (New Object hypothesis). In the present experiment, these two accounts were examined, and the effect of perceptual continuity on saccade guidance was then used to investigate the role of object color in determining continuity.

Experiment 1

The goal of Experiment 1 was first to determine whether saccades to targets that have been previewed in the same or a different location reflect either attentional capture by new perceptual objects or attentional biases toward stimuli that match the contents of visual working memory. An additional goal was to determine how this effect changes when the color of the stimulus is altered such that it no longer matches its appearance when it was first encountered. To test this, participants began each trial by fixating a cross at the center of the computer screen. Two boxes were also presented, above and below the cross. A preview display was then presented; because previous work has suggested that the number of episodic representations that can be simultaneously maintained is quite limited (e.g., Henderson & Anes, 1994), the preview display in Experiment 1 consisted of a single colored letter within one of the two boxes. The letter then disappeared; following a brief delay, a single colored target letter was presented in one box, and a black number was presented in the other box. The participant's task was to make a saccade to fixate the letter as soon as it appeared. The number was intended to provide a stimulus that would compete with the target for attention, in case such competition is necessary for the expression of visual working memory guidance (e.g., Soto et al, 2005).

The location of the target either matched (SO condition) or did not match (DO condition) its previewed location. If saccades to the target are primarily affected by attentional biases that favor stimuli matching the contents of working memory, then responses should be faster in the SO condition than in the DO condition. If, on the other hand, saccades are facilitated when the target is a new perceptual object, then responses should be faster in the DO condition than in the SO condition.

Of particular interest is the effect of changing the color of the letter on the observed RT difference. If color is integrated into the object's episodic representation, then changing the color should substantially reduce or eliminate the difference between the SO and DO conditions. This is true regardless of the source of the difference; in either case, changing the stimulus so that it no longer matches its representation should eliminate the effect. If the effect reflects a bias to attend to items that match the contents of working memory, then the effect should be diminished by color change because neither SO target nor the DO target will match its stored representation. In contrast, if the effect reflects a bias to attend to new perceptual objects, then it should be diminished by color change because both the SO and DO targets will trigger the creation of a new object file when their color fails to match that of their stored representations.

Tas, Dodd, and Hollingworth (2012) have recently presented evidence that changing object color can reduce IOR. Participants in their study saw an initial display consisting of two colored discs, and were cued to fixate one of the discs before a second cue drew their fixation back to the center of the screen. The discs then changed location before a target display in which one of the discs was cued for fixation. The color of the disc either matched or did not match its color in the first display. In the most critical result, Tas et al reported significant IOR that was eliminated when the color of the target disc changed.

On the basis of these data, Tas et al (2012) argued that surface features such as color play an important role in establishing object continuity. It is worth noting, however, that color was an especially important object feature in the Tas et al study. Indeed, color and location were the only features that existed to distinguish one stimulus from other stimuli in the display. While color may be important for the representation of colored discs, it is not clear whether color is an essential part of the episodic representation of more meaningful objects. Gordon and Vollmer (2010), for example, found that changing the color of letter stimuli within the reviewing paradigm did not disrupt perceptual continuity, and argued that color is not essential to the representation of meaningful objects unless the color helps to define the object's identity. As argued earlier, however, this result may reflect the fact that the identification task that is typically used in the reviewing paradigm renders the representation of an object's surface features less useful. Experiment 1, which uses a task that does not favor the representation of particular object features, represents a clearer test of whether episodic representations of identifiable objects include surface features such as color.

Method

Participants—Eighteen undergraduate students at North Dakota State University participated in this study in exchange for course credit. All participants had normal or corrected-to-normal vision.

Stimuli—The stimuli consisted of 16 letters from the English alphabet. Of these, six (A, N, Q, R, S, and T) were used in practice trials and ten (B, C, D, F, G, H, J, K, M, and P) were used in experimental trials. The letters occurred equally often across the experimental trials. The average size of the letters was 4.0° vertically and 3.5° horizontally. Letters were presented in one of four colors (blue, green, red, and yellow) against a light gray background. Letters, which do not have a diagnostic color, were used as stimuli in order to test representations of object color when color is not critical to the object's identity. Furthermore, the same letters and colors were previously used by Gordon and Vollmer (2010) to examine episodic representation of object color using a the more traditional reviewing paradigm.

Apparatus—Stimuli were presented at a resolution of 1024 × 768 pixels on an NEC MultiSync FP2141SB color monitor, with a refresh rate of 75 Hz. Participants viewed the screen from a distance of 57 cm with a chin rest to reduce head movement. At this distance, the size of the total display area was 32° vertically and 45° horizontally. The fixation cross located in the center of the screen had a height and width of 0.6°. Participants' eye movements were recorded using a tower-mounted EyeLink 1000 eyetracker (SR Research Ltd., Mississauga, Ontario, Canada) configured to sample eye position at 1000 Hz. The eyetracker was calibrated at the beginning of the experiment and a drift correction was performed at the start of each trial.

Procedure—Participants initiated the trial sequence by focusing on a fixation cross at the center of the screen and pressing the "Enter" key on the keyboard. Following a 500 ms interval, a letter appeared on the screen, above or below the fixation cross (location varied randomly from trial to trial). The distance from the fixation cross to the center of the letter

was 4.6°. The letter was presented within a square box, measuring 6.3° on each side; a second square box, which did not contain a letter, was presented in the same location on the opposite side of the fixation cross. As in previous studies (e.g., Gordon & Irwin, 1996, 2000; Henderson, 1994), the boxes provided continuity across successive displays within the trial.

After a delay of 1000 ms, the letter disappeared from the screen, leaving only the boxes visible for 500 ms. A single target letter was then presented within one box, and the subject's task was to fixate the letter when it was presented. A non-target object (a black digit between 1 and 8) was presented within the other box. A saccade was detected when the participant moved his or her eyes to fixate the character within either the correct or incorrect box. Reaction time was measured from the onset of the target until the onset of the saccade to one of the two boxes. On a small percentage of trials (described below), participants moved their eyes to fixate on one of the potential target locations prior to the onset of the target display. Those trials were excluded from the analysis, and a message was presented on the screen reminding participants to keep their eyes fixated at the center of the screen until the target display appeared.

There were two experimental conditions used to define the object-specific preview effect that has typically been taken as evidence of object continuity (e.g., Kahneman, Treisman, & Gibbs, 1992). In the same-object (SO) condition, the preview and target letters were presented within the same location (i.e., the same box) in both displays. In the different-object (DO) condition, the preview and target letters were presented in different locations. Experiments examining object continuity have often included a third ("no-match") condition, in which the target does not appear in the preview display, in order to assess preview effects that reflect general priming of type representations. Because such priming was not of theoretical interest in the present study, the design of the present study, like that of many other studies within the episodic representation literature (e.g., Gordon et al, 2008; Gordon & Vollmer, 2010), did not include a no-match condition. The color of the target letter was also manipulated; when the target appeared, its color either matched (50% of trials) or did not match (50% of trials) its color in the preview display.

Each subject completed one block of 12 practice trials followed by two blocks of 160 experimental trials each.

Results

Before analyzing saccade RTs, the data were trimmed by eliminating latencies less than 50 ms, greater than 1500 ms, and those that differed by more than 2.5 standard deviations from that subject's mean RT for that condition (SO or DO) and color (same or different). These criteria eliminated 1.9% of the trials from analysis. Trials in which either potential target location was fixated prior to the onset of the target were also eliminated from subsequent analyses; this criterion eliminated an additional 6.1% of trials. The remaining data were then analyzed in a 2 (condition) $\times$ 2 (color) ANOVA.

Mean RTs and error rates are presented in Table 1. In the analyses that follow, all effects are significant at the 0.05 level, except as otherwise noted. The results of an ANOVA performed on the RT data revealed a main effect of condition, $F(1, 17) = 182.6$, $MSE = 178$, $\eta_p^2 = 0.915$,

as participants responded more slowly in the SO condition ($M = 294$ ms) than in the DO condition ($M = 251$ ms). Changing the letter's color had no effect on RT, $F(1, 17) < 1$, $MSE = 115$, $\eta_p^2 = 0.039$. Importantly, there was no interaction of condition with color change, $F(1, 17) < 1$, $MSE = 146$, $\eta_p^2 = 0.000$; the difference between the SO and DO conditions was as large when letter color changed ($M = 43$ ms) as when it stayed the same ($M = 43$ ms). Post-hoc comparisons carried out using the Tukey's HSD test confirmed that the difference between the SO and DO conditions was significant in both the same-color, and different-color conditions (i.e., an object-specific preview effect was observed regardless of whether or not color changed). In contrast, there was no significant difference between the SO/same-color and SO/different-color conditions, or between the DO/same-color and DO/different-color conditions.

Overall, participants made errors (which involved moving their eyes to fixate the digit rather than the target letter) on 7.7% of trials. Similar to the analysis of the RT data, an ANOVA performed on the error data revealed an effect of condition, $F(1, 17) = 7.8$, $MSE = 64.1$, $\eta_p^2 = 0.315$, but no effect of color change, $F(1, 17) = 2.8$, $p > 0.05$, $MSE = 6.9$, $\eta_p^2 = 0.143$, and no interaction, $F(1, 17) < 1$, $MSE = 5.4$, $\eta_p^2 = 0.004$. Consistent with the RT data, participants made more errors in the SO condition ($M = 10.3\%$) than in the DO condition ($M = 5.0\%$); post-hoc comparisons using the Tukey's HSD method revealed that this difference was significant in both the same-color and different-color conditions.

Discussion

The primary purpose of Experiment 1 was to examine how saccades made to an object are affected by prior exposure to the object in either the same or a different location. Two outcomes were possible. First, the results might have reflected a bias in favor of the object when it appeared in the same location, reflecting a match between the target and its representation in visual working memory; previous work has suggested that stimuli that match the contents of working memory are more likely to be attended. Alternatively, the results might have reflected a bias to attend to a new perceptual object following a disruption of perceptual continuity (in the different-object condition). The results were clearly consistent with the latter prediction, as saccade latencies were shorter when fixating an object appearing in a previously unoccupied location than when fixating an object presented at the same location in both displays.

The finding that color change did not reduce or eliminate this effect suggests that color is either not part of the object's episodic representation or does not play a role in the processes (e.g., comparison of the target object) with that underlie perceptual continuity. Further evidence in support of this argument is that changing color alone was not sufficient to create a new perceptual object (i.e., there was no difference between the SO, same-color condition and the SO, different-color condition). Thus, the results of Experiment 1 suggest that, even when participants are not required to explicitly identify objects in a scene, object identity, but not color, is essential to episodic object representations.

Experiment 2

A potential objection to this conclusion arises from the fact that the target display on each trial contained two potential saccade targets: the colored letter to which a saccade was to be directed, and a black number that served as a distractor. Because previous work has suggested that inputs from visual working memory might play a role in resolving competition among objects within a scene (e.g., Soto et al, 2005), the distractor was included in order to provide the most favorable conditions for testing the VWM Guidance Hypothesis. That is, it was thought that the selection of an object matching the contents of visual working memory might be more likely when multiple objects compete for attention. Nonetheless, this decision carried a significant cost: distinguishing the target and the distractor required participants to identify the target's category (because only the target was a letter), color (because the distractor was always black), or both. If participants were more likely to make the selection by identifying the target's category, then the task would implicitly make identity more task-relevant than color, contrary to the experimental goals.

In Experiment 2, only a single target letter was presented in the target display, without any distractor objects to compete for attention. Replication of the results of Experiment 1 would provide additional support for the argument that identity, but not color, is essential to episodic object representation. Furthermore, it would strengthen the argument by using a procedure in which object identification is neither explicitly nor implicitly required to perform the task.

Method

Subjects—Twenty-four undergraduate students at North Dakota State University participated in this study in exchange for course credit. All subjects had normal or corrected-to-normal vision.

Stimuli—Experiment 2 used the same stimuli as Experiment 1. As in Experiment 1, letters occurred equally often across the experimental trials.

Apparatus—The apparatus used in Experiment 2 was the same as in Experiment 1.

Procedure—The procedure was the same as in Experiment 1, with the exception that the target display contained only a single colored letter, rather than one colored letter and one black digit. As in Experiment 1, there were two continuity conditions (same object, or SO, and different object, or DO) and two color change conditions (same or different). Each participant completed one block of 12 practice trials followed by two blocks of 160 experimental trials each.

Results

Before analyzing saccade RTs, the data were trimmed by eliminating latencies less than 50 ms, greater than 1500 ms, and those that differed by more than 2.5 standard deviations from that subject's mean RT for that condition (SO or DO) and color (same or different). These criteria eliminated 5.6% of the trials from analysis. Trials in which either potential target location was fixated prior to the onset of the target were also eliminated from subsequent

analyses; this criterion eliminated an additional 5.9% of trials. The remaining data were then analyzed in a 2 (condition) $\times$ 2 (color) ANOVA.

Mean RTs and error rates are presented in Table 2. In the analyses that follow, all effects are significant at the 0.05 level, except as otherwise noted. Consistent with Experiment 1, the results of an ANOVA performed on the RT data revealed a main effect of condition, $F(1, 23) = 62.0$, $MSE = 936$, $\eta_p^2 = 0.729$, with participants responding more slowly in the SO condition ($M = 274$ ms) than in the DO condition ($M = 224$ ms). There was no effect of color change, $F(1, 23) = 1.8$, $MSE = 334$, $\eta_p^2 = 0.073$. Consistent with Experiment 1, there was also no interaction of condition with color change, $F(1, 23) = 2.3$, $MSE = 207$, $\eta_p^2 = 0.091$; the difference between the SO and DO conditions was as large when letter color changed ($M = 45$ ms) as when it stayed the same ($M = 54$ ms). Post-hoc comparisons carried out using the Tukey's HSD test confirmed that the difference between the SO and DO conditions was significant in both the same-color, and different-color conditions (i.e., an object-specific preview effect was observed regardless of whether or not color changed). In contrast, there was no significant difference between the SO/same-color and SO/different-color conditions, or between the DO/same-color and DO/different-color conditions.

Overall, participants made errors (which involved moving their eyes to fixate the non-target location) on 6.3% of trials (this appears to be lower than the error rate in Experiment 1, which there were two potential target stimuli in the display). An ANOVA performed on the error data revealed no effect of condition, $F(1, 23) < 1$, $MSE = 20.1$, $\eta_p^2 = 0.000$, or of color change, $F(1, 23) < 1$, $MSE = 10.9$, $\eta_p^2 = 0.14$, and no interaction, $F(1, 23) < 1$, $MSE = 10.4$, $\eta_p^2 = 0.011$.

Discussion

The design of Experiment 2 differed from that of Experiment 1 in that only a single potential target object was present within each target display; thus, it was not necessary to distinguish the target from a distractor object on the basis of either identity or color. Nonetheless, the results of Experiment 1 were replicated. Consistent with the New Object hypothesis (but not with the VWM Guidance hypothesis), a target was fixated more quickly when it appeared in a new location than when it appeared in a location consistent with its representation in visual working memory. Furthermore, the finding that this effect was not reduced or eliminated by a change in the object's color supports the argument that while identity is essential to episodic object representation, color is not.

The lack of an effect of color change, while consistent with previous studies using the reviewing paradigm, is inconsistent with Tas et al's (2012) finding that color change reduces IOR – a finding that the authors attributed to a disruption of perceptual continuity in the color change condition. There are several important differences between the experiments, however, that may contribute to the divergent results. Perhaps most critically, color was an especially salient and important feature within Tas et al's displays. Each display, for example, consisted of two discs that were distinguishable only by their color and location. In contrast, each display in Experiments 1 and 2 contained only a single colored item,

rendering color less important as a means of defining or differentiating the stimuli. In Experiment 3, the effect of color change on the bias to attend to new perceptual objects was tested when color was made more relevant to object individuation.

Experiment 3

In Experiments 1 and 2, letter color was irrelevant to the participant's central task, but was also irrelevant to differentiating the object from other elements within the scene. In contrast, Tas et al (2012), who showed effects of color change on IOR using simpler stimuli, presented two colored objects on each trial. The context in which the items are presented may be significant; indeed, Mitroff, Arita, & Fleck (2009) have demonstrated contextual effects on episodic object representation. Because the presence of a second colored letter makes letter color more salient and relevant to object individuation, it was expected that letter color would play an enhanced role in object representation and in preserving object continuity in Experiment 3.

Method

Subjects—Twelve undergraduate students at North Dakota State University participated in this study in exchange for course credit. All subjects had normal or corrected-to-normal vision.

Stimuli—Experiment 3 used the same stimuli as Experiment 1. Although more letters appeared within each trial in Experiment 3, it was still the case that all letters occurred equally often, as targets and distractors, across the experimental trials.

Apparatus—The apparatus used in Experiment 3 was the same as in Experiment 1.

Procedure—The procedure was the same as in Experiment 1, with the exception that the preview display contained two colored letters, rather than one. Both letters were drawn from the set of letters that were used as targets. Each was colored either red, green blue, or yellow, and their colors did not match. On trials in which the color of the target did not match its previewed color, the target's color was also different than the color of the other preview letter.

As in Experiment 1, there were two continuity conditions (same object, or SO, and different object, or DO) and two color change conditions (same or different). Each participant completed one block of 12 practice trials followed by two blocks of 160 experimental trials each.

Results

Before analyzing saccade RTs, the data were trimmed by eliminating latencies less than 50 ms, greater than 1500 ms, and those that differed by more than 2.5 standard deviations from that subject's mean RT for that condition (SO or DO) and color (same or different). These criteria eliminated 2.7% of the trials from analysis. Trials in which either potential target location was fixated prior to the onset of the target were also eliminated from subsequent

analyses; this criterion eliminated an additional 7.5% of trials. The remaining data were then analyzed in a 2 (condition) $\times$ 2 (color) ANOVA.

Mean RTs and error rates are presented in Table 3. In the analyses that follow, all effects are significant at the 0.05 level, except as otherwise noted. The results of an ANOVA performed on the RT data revealed no main effect of condition, $F(1, 11) < 1$, $MSE = 2180$, $\eta_p^2 = 0.060$, or of color change, $F(1, 11) < 1$, $MSE = 173$, $\eta_p^2 = 0.024$. Importantly, however, there was a significant interaction of condition with color change, $F(1, 11) = 13.7$, $MSE = 170$, $\eta_p^2 = 0.554$. Post-hoc comparisons carried out using the Tukey's HSD method revealed that each condition in which the target's features differed from its preview (i.e., the SO/different-color, DO/same-color, and DO/different-color conditions) produced significantly shorter saccade latencies than the condition (SO/same-color) in which none of the target's features had changed. This suggests that a change in either identity or color was sufficient in Experiment 3 to signal the creation of a new perceptual object, to which attention was then drawn. The three change conditions did not differ significantly from each other.

Overall, participants made errors (which involved moving their eyes to fixate the digit rather than the target letter) on 11.9% of trials. An ANOVA performed on the error data revealed no effect of condition, $F(1, 11) < 1$, $MSE = 6.8$, $\eta_p^2 = 0.014$, or of color change, $F(1, 11) = 1.6$, $p > 0.05$, $MSE = 8.2$, $\eta_p^2 = 0.092$, and no interaction, $F(1, 11) = 1.5$, $p > 0.05$, $MSE = 17.2$, $\eta_p^2 = 0.171$.

Discussion

The results from the same-color condition in Experiment 3 were consistent with those of Experiments 1 and 2 in demonstrating a bias to attend to new perceptual objects, as participants made slower eye movements to a letter appearing in its previously presented location than to a letter appearing in a location that was previously occupied by a different letter. Importantly, this effect was eliminated when the target's color was different than its previewed color. This result suggests that color is part of the object's episodic representation, and plays a role in the processes that underlie perceptual continuity. Consistent with this explanation, analyses also revealed a *same-color benefit* on saccade latencies: when object identity remained constant (in the SO condition), saccades were made more quickly to targets whose color changed than to targets whose color did not. That color had such an effect in Experiment 3, but not in Experiments 1 and 2, is consistent with previous findings that object file representations are sensitive to the context in which objects appear (e.g., Mitroff, Arita, & Fleck, 2009; Schreij & Olivers, 2013). This issue is discussed further below.

General Discussion

Given the important role that episodic object representations are thought to play in visual cognition, such representations have received considerable attention over the last several years. In particular, the question of which properties are included in an object's representation and contribute to maintaining perceptual continuity has been the subject of

much of this work (e.g., Gordon & Irwin, 1996, 2000; Gordon & Vollmer, 2010; Gordon, Vollmer, & Frankl, 2008; Henderson, 1994; Henderson & Anes, 1994). Typically, however, these studies have employed a paradigm in which one object property, identity, is made task relevant, while other properties, such as orientation, color, or letter case, are irrelevant to primary task performance. While results from these studies have generally suggested that identity, and not other object properties, is a critical part of object representation, one may reasonably wonder if this reflects the general nature of episodic representations, or is, rather, a consequence of the particular task which has dominated the literature.

The present study represents a new approach to studying episodic object representation, in which no object feature (save location) is more or less relevant for performing the primary task. Participants began each trial by viewing one (Experiments 1 and 2) or two (Experiment 3) briefly-presented colored letters, presented above and below fixation. The letters disappeared, then a single letter appeared within one of the two locations. The similarity of the target to the stimulus that was previewed in the same location was manipulated. In the same-object (SO) condition, the target's identity matched the identity of the preview letter that appeared within the same location; in the different-object (DO) condition, the target did not appear in a location that contained the same letter in the preview display. The participants' task was to make an immediate saccade to fixate the target when it appeared, and the latency with which they executed the saccade was recorded and served as the dependent variable. Because no other task was required, there was no reason that object identity should be considered more relevant to performance than object color.

Two potential outcomes were identified, either of which would permit an investigation of the features that make up an episodic object representation. First, the Visual Working Memory Guidance hypothesis suggested that attention would be drawn to the location of the target when it matched the stimulus that was presented in the same location within the preview display. Such a result would be consistent with previous work (e.g., Soto et al, 2005) showing that attention is guided quickly to the location of stimuli that match the contents of visual working memory, where episodic object representations are thought to reside (Gajewski & Brockmole, 2006). Under this account, saccade latencies should be shortest when the target and the same-location preview match exactly (i.e., have the same identity and color). If letter color is not represented in episodic representations, then saccade latencies would be equally short even when letter color changes (as long as identity remains the same); in contrast, saccade latencies should be longer following a color change if color is part of episodic object representations.

In contrast to the VWM Guidance hypothesis, the New Object hypothesis predicted that attention, and the eyes, would be drawn to the location of an object when it failed to match the preview stimulus that was presented in the same location. Such conditions should necessitate the creation of a new object representation for the target item (Kahneman, Treisman, & Gibbs, 1992), and previous work has shown that the creation of a new object representation captures attention (Hillstrom & Yantis, 1994; Yantis & Hillstrom, 1994). According to this account, when stimulus color is constant, saccade latencies should be shorter when the target identity is different than the identity of the same-location preview stimulus than when the identities of the stimuli in the same location match. If stimulus color

changes, and if color is part of episodic object representations, then the preview and target stimuli should fail to match even when their identities are the same; color change should always prompt the creation of a new representation, and so saccade latencies should be long regardless of whether or not the object identities match.

The results of the present investigation provide support for the New Object hypothesis. In each experiment, when object color did not change, saccades were executed more quickly in order to fixate the target in the DO condition than in the SO condition. This clearly suggests, consistent with previous work (e.g., Gordon & Irwin, 1996, 2000; Gordon & Vollmer, 2010), that identity is a fundamental part of an object's episodic representation. Changing the identity has consequences, with a change in identity (in the DO condition) signaling the appearance of a new perceptual object, which draws attention. Importantly, the results suggest further that color, too, is part of an object's episodic representation, consistent with previous studies that have not used the reviewing paradigm (e.g., Johnson et al, 2008; Richard et al, 2008; Tas et al, 2012). There was no evidence of this in Experiments 1 or 2, in which color change had no impact on attentional guidance. That is, in both experiments, a change in object color was not sufficient to signal the appearance of a new perceptual object. In Experiment 3, however, a change in either identity or color (or both) signaled the appearance of a new object, and targets that changed along either dimension were fixated more quickly than targets that did not change at all. The key difference between the experiments may have to do with context; when differently-colored letters are present in the display, as in Experiment 3, this appears to make it more likely that a letter's color will be represented in its episodic representation.

Factors Influencing Episodic Object Representation

Although contextual influences on episodic object representation have received relatively little attention, the present finding is consistent with other work suggesting that the same object may be represented differently when presented within different contexts (e.g., Mitroff, Arita, & Fleck, 2009; Schreij & Olivers, 2013). Mitroff, Arita, and Fleck (2009), for example, examined the extent to which object files are constrained by the principle of boundedness, which states that "an object must have a single continuous boundary" (p. 198). To test this, Mitroff et al used a version of the reviewing paradigm in which the frames that contained the preview and target letters were defined either by clearly drawn borders, or by shapes that induced illusory contours. When presented on their own, illusory-defined objects were unable to support the construction or maintenance of object files, as reflected by the lack of a significant object-specific preview benefit when responding to the target. Interestingly, however, Mitroff et al found that illusory-defined objects were able to produce object-specific preview benefits when they were presented within a block of trials that also contained objects with physical borders. On the basis of these results, and the results of a subsequent experiment, Mitroff et al concluded that the context in which an object appears may affect its episodic representation. This appears to be the case in the present experiment as well, with color being represented only for letters appearing in the context of differently-colored items.

Why should context have such an effect on object representation? A possible explanation has to do with biases that favor the representation of features that are used to discriminate between objects presented simultaneously within a scene. According to this explanation, the presence of a second, differently-colored object in the preview display enhances the importance of color during encoding by making it one of the features by which stimuli in the scene are discriminated. This may have important representational consequences. Sigala and Logothetis (2002), for example, have provided evidence of enhanced neural processing of features that are important to categorizing objects; Wagar and Dixon (2005) have shown that enhanced processing of features critical for categorization occurs during encoding, and that those features are more likely, as a result of this enhanced encoding, to be represented in visual working memory.

It should be noted that similar contextual effects have been observed in perceptual learning experiments. Mundy et al (2007), for example, have shown that, when presented with stimuli that have both shared and unique features, greater attentional weight is given to the unique features, affecting perceptual learning. De Zilva and Mitchell (2012) have argued that this and similar results reflect an underlying bias that enhances the memory representation of non-shared features among multiple objects. Taken together, these studies suggest that color is represented in Experiment 3 because the presence of differently-colored stimuli enhanced its relative importance; color was relatively less important in Experiments 1 and 2 because of the absence of similar objects whose discrimination might be impacted by color. In contrast, object identity appears to be a more fundamental aspect of episodic representation, and its inclusion does not depend on the presence of other stimuli in the scene.

In addition to effects of context, episodic object representations may also be subject to influences from the requirements of the participants' primary task, offering an explanation for inconsistent findings in studies that have used the reviewing paradigm (e.g., Gordon & Vollmer, 2010) and those that have not (e.g., Richard et al, 2008; Tas et al, 2012). Gordon and Vollmer (2010) used the same stimuli as were used in the present study, and, like Experiment 3, used preview displays containing two colored letters. Nonetheless, although object-specific preview effects were obtained in their study, those effects were not reduced or eliminated when the target's color differed from its color in the preview display. In contrast, color change did have such an effect in the current Experiment 3. The most significant way in which the two studies differ is in the task that participants performed. In particular, Gordon and Vollmer's participants were asked to identify the target when it appeared, which had the effect of making object identity more important within the experimental context than other object features. By having participants instead fixate the target when it appears, object identity and color are made equally important to task performance; this shift away from privileging object identity appears to have the consequence of encouraging the inclusion of features other than identity in episodic representations. An advantage of the new approach taken in the present study, then, is to reveal principles of object representation that are relatively free from task demands that favor one feature over another.

Attentional Guidance by Visual Working Memory

Given the growing evidence that attention is guided to the location of objects that match the contents of visual working memory (e.g., Cosman & Vecera, 2011; Downing, 2000; Soto et al, 2005), and the evidence that episodic object representations reside within visual working memory (Gajewski & Brockmole, 2006), it is perhaps surprising that the present experiments did not reveal a bias to fixate objects that matched their representations. That is, one might have expected to see shorter latencies in the same-object condition than in the different-object condition – the opposite of what was found in the present study. Though additional work is certainly needed to identify the conditions under which attention is guided to new or old objects, it is worth noting that experiments demonstrating guidance by visual working memory have typically done so using a much different task than was used in the current experiments. Most often, such effects have been demonstrated within the context of a visual search task, in which participants are shown an item to hold in working memory, then are required to search through a display containing multiple distractors to determine whether a target is present. As others have noted (e.g., Dodd, van der Stigchel, & Hollingworth, 2009), visual search may engage unique processes that are not necessarily reflected in performance of other tasks.

For example, theories of visual search typically argue that search involves the maintenance of target templates in visual working memory that can be used to provide top-down guidance of attention to potential targets in the display, and to determine whether or not a particular display item matches the target (e.g., Desimone & Duncan, 1995; Duncan & Humphreys, 1989). Thus, interactions of attention and visual working memory, with attention biased to select items matching working memory contents, are an essential part of the search process (at least when targets are not consistent from trial to trial; see Woodman, Luck, and Schall, 2007). Under such circumstances, one might expect to see selection of items matching VWM contents during visual search, even when the item being held in visual working memory doesn't represent the target itself; and indeed, this has been shown to be the case (e.g., Soto et al, 2005). In the present study, however, participants do not need to search for the target or match it with a stored template in order to perform the task effectively. Under these conditions, there may be little opportunity for interactions between visual working memory and attention that will produce biases in favor of VWM contents. Instead, the present task is more favorable to demonstrating a bias toward new perceptual objects – a bias that is less likely to be expressed within a typical visual search task containing a large number of new objects with the onset of each display.

Conclusion

The present investigation identifies a new approach to studying episodic representation – one that makes all object features equally relevant to task performance. The results suggest that this is a potentially fruitful approach to investigating the general principles that underlie such representation. The results of two experiments using this approach suggest that episodic object representations include information concerning object identity, but may also include representations of object color, even when color is irrelevant to the object's identity.

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Table 1

Mean saccadic reaction times and preview effect (in ms) and error rates (in percentages) in Experiment 1

Condition	Color	
	Same	Different
Same-Object	293 (9.9)	295 (10.8)
Different-Object	250 (4.4)	252 (5.6)
Preview Effect	-43 (-5.5)	-43 (-5.2)

Table 2

Mean saccadic reaction times and preview effect (in ms) and error rates (in percentages) in Experiment 2

Condition	Color	
	Same	Different
Same-Object	278 (6.7)	269 (6.0)
Different-Object	224 (6.3)	224 (6.3)
Preview Effect	-54 (-0.4)	-45 (0.3)

Table 3

Mean saccadic reaction times and preview effect (in ms) and error rates (in percentages) in Experiment 3

Condition	Color	
	Same	Different
Same-Object	300 (11.3)	284 (12.3)
Different-Object	275 (12.9)	287 (10.2)
Preview Effect	-25 (1.6)	3 (-2.1)