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Evidence for Preserved Representations in Change Blindness

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People often fail to detect large changes to scenes, provided that the changes occur during a visual disruption. This phenomenon, known as ''change blindness,'' occurs both in the laboratory and in real-world situations in which changes occur unexpectedly. The pervasiveness of the inability to detect changes is consistent with the theoretical notion that we internally represent relatively little information from our visual world from one glance at a scene to the next. However, evidence for change blindness does not necessarily imply the absence of such a representation—people could also miss changes if they fail to compare an existing representation of the pre-change scene to the post-change scene. In three experiments, we show that people often do have a representation of some aspects of the pre-change scene even when they fail to report the change. And, in fact, they appear to ''discover'' this memory and can explicitly report details of a changed object in response to probing questions. The results of these real-world change detection studies are discussed in the context of broader claims about change blindness.

Our experience of a rich, stable visual world often leads to the intuitive belief that our representations of that world are correspondingly detailed and precise. But increasing evidence for ''change blindness,'' the inability to detect large changes to scenes from one glance to the next, has inspired claims that little to no information about the world is preserved in visual short term memory (e.g., O'Regan, 1992; Rensink, 2000a, 2000b). Such claims have some historical precedents (e.g., Gibson, 1986/1979; Hochberg, 1986; Stroud, 1955), but they do not necessarily follow from change blindness. Change blindness could occur for many reasons, even when observers have representations of the pre-change scene (Simons, 2000b). For example, change blindness could reflect a failure to compare representations of the pre- and post-change scene. Here, we present evidence that supports this possibility by showing that some subjects who fail to report a change can subsequently report features of the pre-change object when asked.

Almost all evidence for change blindness derives from situations in which a change is produced during a visual disruption or distraction (see Simons, 2000b; Simons & Levin, 1997 for reviews) which serves to mask the transient that could otherwise attract attention to the change. In essence, such change detection tasks are akin to

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asking observers to report their experience of a visual illusion: they assess how the visual system breaks down, and in so doing, reveal the basic assumptions of the visual system. By ‘‘breaking’’ a system, we can often gain a better understanding of how that system normally functions. Although changes typically are accompanied by a change signal, by producing changes without such a signal (however unnatural the disruption), we can better determine how much information is represented across views. When a change produces a signal, we do not need to compare the before and after representations to detect the change—we only need to detect the signal. In contrast, when the change produces no such signal, successful change detection requires a representation of the feature of the original display that changed as well as a comparison of that representation to the changed display. That is, successful change detection requires that something be preserved from the first display.

In a study using motion picture cuts as a visual disruption, nearly two thirds of unsuspecting observers miss a change to the identity of the central actor (Levin & Simons, 1997). In fact, observers often do not notice when a stranger they are talking to is surreptitiously replaced by a different person (Levin, Simons, Angelone, & Chabris, in press; Simons & Levin, 1998). In one such study, an experimenter approached a pedestrian to ask for directions. As the pedestrian provided directions, two people carrying a door passed between the experimenter and the pedestrian, temporarily blocking the pedestrian’s view. During this disruption, the first experimenter was replaced by a different person (Simons & Levin, 1998). Under these conditions, half of the observers did not realize that they were talking to a new person after the door passed by. Similar levels of change blindness occur when the pedestrian is asked to take a photograph of the experimenter and the person-switch occurs while the pedestrian is composing the photograph (Levin et al., in press, Experiment 2). Blindness to such real-world changes occurs even when observers know they are in an experiment, provided that they do not know that a change is about to happen (Levin et al., in press, Experiment 2). In all of these experiments change blindness was defined as the failure to spontaneously report any aspect of the change when asked open-ended questions. For example, after viewing a video of a change, participants were asked to describe everything that they had seen. For the real-world changes, they were asked whether they noticed anything unusual and/or whether they had noticed anything change.

Change blindness also occurs under laboratory conditions when participants are actively looking for changes. For example, observers often miss changes to photographs provided that the change is made during a saccade (e.g., Grimes, 1996; Henderson & Hollingworth, 1999; McConkie & Currie, 1996), a flashed blank screen (e.g., Pashler, 1988; Phillips, 1974; Rensink, O’Regan, & Clark, 1997; Simons, 1996), a blink (O’Regan, Deubel, Clark, & Rensink, 2000), or some other visual disruption (e.g., O’Regan, Rensink, & Clark, 1999; Rensink, O’Regan, & Clark, 2000). When the original and changed version alternate repeatedly, separated by a blank screen, observers often require many cycles of the original and changed image to find changes (Rensink et al., 1997). The typical participant experience in both the laboratory and real world experiments is consistent—they do not notice the changes. However, intentional, laboratory change detection tasks and incidental, real-world tasks might well reflect the operation of distinct encoding mechanisms (Simons &

Mitroff, 2001). In intentional tasks, observers actively try to detect changes. Consequently, they likely encode and retain as much information from each glance of a scene as possible. In contrast, participants in incidental tasks are unaware of an impending change, so they are not actively searching for a change. Intentional tasks measure how well observers can detect changes when they try to, whereas incidental tasks might better reflect the amount of information retained and compared spontaneously under more natural conditions. We will return to this distinction in the general discussion.

Given the variety of tasks that induce change blindness and the pervasiveness of the phenomenon, both in the laboratory and in real-world situations, many researchers have been tempted to conclude that change blindness reflects a failure to represent the details of scenes (see Simons, 2000b, for discussion). We fail to detect changes when they occur during a visual disruption, and that failure seems to reflect the visual system's assumption that the world is unchanging. A natural inference from this assumption is that our experience of a stable and detailed visual world does not derive from a detailed internal model of the world. Properties of objects generally do not change instantaneously during disruptions (i.e., a conversation partner is unlikely to be replaced by another person). Consequently, our visual system might simply assume that the world is stable without wasting effort representing much of the detail of the world. Essentially, we rely on the world as an ''external memory'' (O'Regan, 1992; see also Gibson, 1986/1979; Rensink, 2000a; Stroud, 1955), checking the details whenever we need them, and assuming that nothing changes without a signal.

Such a model might well explain our experience of a stable world in the face of change blindness. Furthermore, the principles of minimal representation are consistent with a larger body of evidence from the study of visual integration across eye movements (e.g., Irwin, 1991). However, the conclusion that we lack any representation of the world does not follow logically from a finding of change blindness (Simons, 2000b). Change blindness could occur even if observers formed a complete, detailed, and precise representation of the original scene. For example, observers could form representations of each glance at a scene but simply not compare those representations from one instant to the next. Consequently, change blindness could result from the failure to compare representations as well as from a failure to retain a representation. Similarly, change blindness could occur if observers formed an accurate representation of the first view of a scene but never updated that representation, essentially relying on their first impression. Furthermore, even if observers did not form a representation that was accessible to verbal report, they might still form a detailed and precise implicit representation of the scene that could not support conscious change detection (e.g., see discussion in Fernandez-Duque & Thornton, 2000). Change blindness is entirely consistent with the existence of representations of the initial and changed views.

Despite all of these alternatives, the most frequently proposed mechanism for change blindness is that the second version of a scene simply masks or overwrites the original version (Enns & Di Lollo, 2000; Rensink et al., 1997). Change blindness occurs because any representation of the first display that could subserve change detection is eliminated or disrupted by the appearance of the second display (or by the visual disruption). This view is akin to the idea that change blindness results from a failure to represent the pre-change scene. The overwriting account provides an intuitive and plausible explanation for change blindness induced by flashing a blank screen or by repeatedly cycling the original and changed image (the ''flicker task''). In these tasks, observers intentionally search for changes, but the visual disruption apparently prevents them from detecting the change. Phenomenally, the blank screen seems to eliminate any persisting representation of the scene.

The overwriting account also seems to explain performance in some real-world incidental tasks (Levin et al., in press). For example, in one study, pedestrians encountered an unexpected person change while providing directions, and after the interaction they performed a recognition memory task: they viewed 4 photographs, one of which was of the pre-change assistant, and were asked to select the person they had seen. Observers who noticed the change were able to select the pre-change assistant better than would be expected by chance ($M = 63\%$). However, observers who missed the change were substantially worse than those who detected the change ($M = 26\%$), and not significantly better than expected by chance. A second experiment confirmed that pedestrians who noticed the change were better able to recognize the changed people and that pedestrians who missed the change were no better than would be expected by chance. This difference in recognition performance suggests that pedestrians who noticed the change had a better representation of the changing feature(s) than did those who missed the change. However, even chance performance on a recognition lineup task does not require the absence of a representation. Observers who failed to detect the change could have represented many details from the first scene; a photographic lineup does not test all possible representations, and it might not accurately reflect the amount of preserved information. Furthermore, given that the pedestrians did not know they were in an experiment when the change occurred, they might have represented far less than they optimally *could* have represented.

In fact, another recent series of studies suggests that observers do retain some details even when they fail to detect changes (Angelone, Levin, & Simons, 2001). In these studies, observers viewed one of several videos of a person asking for directions. During a camera cut to a different angle, either the actor unexpectedly was replaced by a different person or the properties of objects carried by the actor were changed. After viewing the video, observers reported whether or not they had noticed any changes (in response to a series of questions). They then viewed a photograph of the post-change stimulus and tried to pick the pre-change stimulus from an array of four photographs. Across experiments, between 45 and 95% of participants failed to notice the change. Despite this large variability in the rate of noticing the change, lineup recognition performance was relatively constant across experiments. Furthermore, in most conditions, recognition accuracy was comparable for those participants who did and did not notice the change—both groups recognized the pre-change stimulus more frequently than would be expected by chance (between 40 and 60% of the time, depending on the experiment). This finding suggests that even observers who missed the change often did represent sufficient detail from the pre-change stimulus to be able to select it from an array of similar distractors. Had observers compared this existing representation to the post-change scene, they could have inferred the presence of a change.[2] Thus, change blindness might have resulted from a failure to compare existing representations. Note, however, that observers also could have failed to represent the second actor. If so, then they would fail to detect the change because they would have no features of the second actor to compare to the representation of the first actor (Simons, 2000b).

The goal of the experiments reported here is to explore whether change blindness for a real-world, unexpected change can occur when observers have successfully represented some of the changed details from the pre-change scene. That is, we sought to explore whether change blindness can result from the failure to compare existing representations (see Angelone et al., 2001). Instead of changing the identity of the experimenter as the subjects were providing directions, in these studies we changed a single object that the experimenter was holding. Following the interaction, we asked a series of increasingly specific questions about the change, first giving the opportunity for a spontaneous report of the change (as in prior studies), and then providing more detailed cues to see if the pedestrian would ''discover'' that they did have a memory for the changed object.[3] If change blindness results from complete overwriting of the first scene by the changed scene, then observers should be unable to retrieve any details specific to the pre-change scene. In contrast, if change blindness occurs without complete overwriting of the pre-change scene, then observers might well be able to recall the properties of a changed object when prompted with a useful retrieval cue, even if they did not spontaneously notice the difference.

Note, however, that observers might be able to recall details from the pre-change scene even if overwriting *does* help to account for change blindness. For example, the representation needed for change *perception* might be overwritten, leaving only more abstract or verbal representations. If so, observers might then be able to report the features of an object even if overwriting eliminated the representation necessary for change perception. On the other hand, change detection via *inference* should still be possible if observers can recall some details from the pre-change object. By arguing that preserved representations imply a comparison failure, we acknowledge that change perception might differ from change inference and that overwriting might better explain the elimination of change detection via perception. However, evidence

[2] This kind of recognition test is traditionally considered to be an explicit measure, but most memory researchers would agree that an implicit component could be involved as well. (It is difficult to demonstrate that any explicit measure excludes all implicit influences.) Angelone et al.'s third experiment did collect confidence ratings and found that subjects who missed the change were just as confident in their lineup choices ($M = 4.85$ out of 7 in the ''cue'' condition and 4.86 out of 7 in the ''no cue'' condition) as those who detected the change ($M = 5.3$ in the ''cue'' condition and 4.85 in the ''no cue'' condition). The comparable levels of confidence across subjects suggest that decisions by the two groups resulted from similar explicit access to stored representations.

[3] Schooler (in press) discusses the possibility that memories that were never forgotten can produce a sense of discovery when people remember them some time later. This notion has been used as an alternative way to describe ''recovered'' memories. In the current experiments, we test for memories that observers are momentarily unaware of, but which are brought to awareness by our questioning. Unlike the cases discussed by Schooler and others, our studies are focused on short-term memory for a recently viewed scene. Consequently, direct application of our findings to the ''discovery'' of long-term memories is unwarranted.

for preserved representations of any sort provides a convincing counter-example to the strong form of the overwriting hypothesis in which the pre-change details are entirely replaced. Furthermore, such evidence provides an existence proof that change blindness could result from a mechanism other than overwriting. Whether or not such a mechanism could operate in all change detection tasks is an empirical question.

EXPERIMENT 1

This preliminary experiment was designed to address several methodological issues and to provide an initial test of a related theoretical question. The methodological questions arose because of the departure from previous real-world experiments. Rather than changing the identity of the experimenter, we simply added or removed a single object. Given this different sort of change, we needed to verify that the event would indeed induce some change blindness, but also that it would be noticed by some observers. For change blindness to be interesting, the change must be large enough that it is potentially detectable (see Simons & Levin, 1998). If some observers do detect the change, that would provide confirmation that the change is sufficiently noticeable. Second, the means of inducing the change was different from prior experiments. Given that a smaller disruption is needed to remove or add an object than would be needed to make an identity change, we decided to make the change during a more natural event. The door interruption used in prior experiments tends to be somewhat jarring and might distract observers more than necessary for a smaller change. Consequently, we made the change as a group of people walking down a path passed between the experimenter and the pedestrian. A goal of this experiment was to verify that such a means of inducing a change would be less disruptive and to verify that the change could be made surreptitiously. This method was used in all three experiments.

In addition to exploring whether or not observers would miss this change, the primary purpose of this experiment was to determine whether or not there were any differences in noticing when an object was added to a scene as opposed to when it was removed from the scene. Implicit measures of attention capture suggest that the abrupt appearance of a new object in a display often captures attention (Jonides & Yantis, 1988; Yantis & Jonides, 1984; see Simons, 2000a, for a review). If the presence of a new object captures attention in the real world, then we might expect observers to notice the addition of an object more than the removal of an object (but see Mondy & Coltheart, 2000).

Participants

Fourteen pedestrians provided directions and then answered our experimental questions. Data from 3 of these 14 were not analyzed due to uninterpretable responses ($n = 2$) or familiarity with previous real-world change blindness studies ($n = 1$). A few (uncounted) additional pedestrians either declined to provide directions when approached or declined to answer our questions after the interaction was completed. All participants were thanked, but were not otherwise compensated.

Materials and Procedure

In this experiment, the critical change was the addition or removal of a standard, orange basketball. A female undergraduate assistant who was dressed in athletic clothing approached pedestrians who were walking alone on a path through Harvard Yard and asked them for directions to the gymnasium (Fig. 1a). When a pedestrian began giving directions, a group of eight confederates casually walked down the path while chatting with each other (Fig. 1b). The location for the study was chosen such that some members of the group would have to pass between the pedestrian and the assistant and others would have to pass behind the assistant in order to stay on the path. As the group passed (Fig. 1c), one of the people passing behind the assistant either added the basketball by placing it under the assistant's left arm (*addition condition*) or removed it by taking it away and hiding it from the view of the pedestrian (*removal condition*). Six of the participants were in the addition condition and five

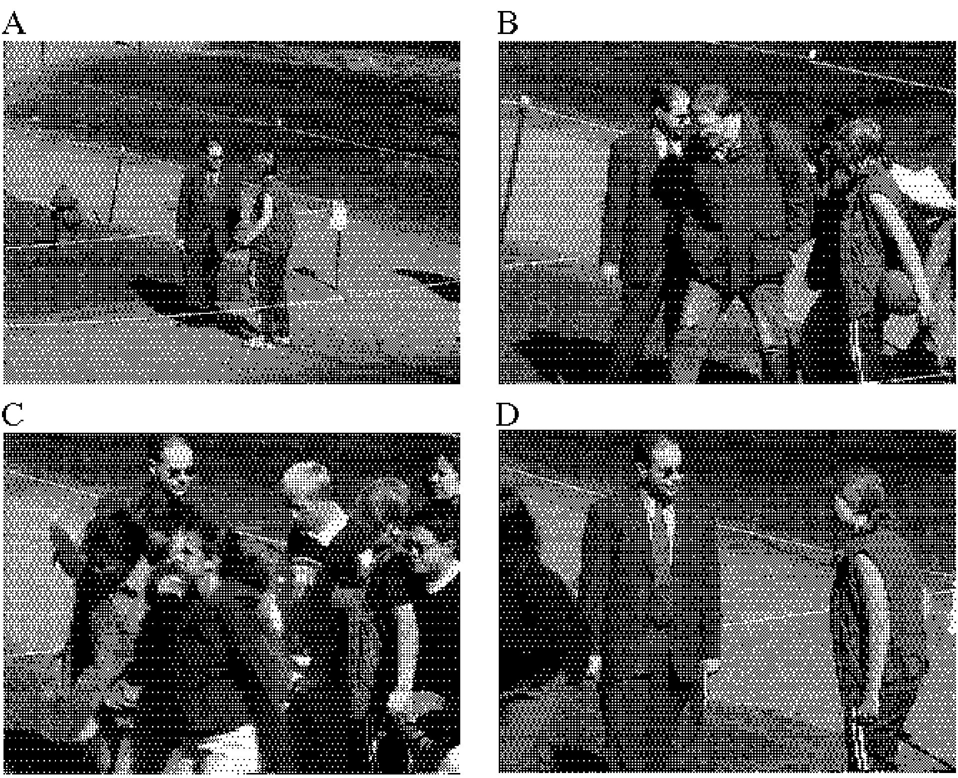

FIG. 1. Four frames depicting the type of change event used in all three experiments. An assistant holding a basketball approaches a pedestrian to ask for directions (A). As the pedestrian provides directions, a group of people walk past, with some people passing between the assistant and the pedestrian and others passing behind the assistant (B). One of the people surreptitiously removes the basketball while the pedestrian's view is occluded (D). The pedestrian continues to provide directions. In Experiments 1 and 2 there was also an ''addition'' condition in which the assistant did not initially have the ball, but surreptitiously received it from the crowd as they walked by.

were in the removal condition. The entire disruption lasted approximately 2–3 seconds, and the exchange of the ball was hidden by the people passing between the assistant and pedestrian.

After the pedestrians finished giving directions, they were told that we were conducting a psychology study about the sorts of things that people pay attention to in the real world. They were then asked if they would be willing to answer a few quick questions about what had just occurred. If they agreed, they were asked the following questions: (1) ‘‘Did you notice anything unusual happen as the crowd of people passed between us? (if yes, please describe),’’ (2) ‘‘Did you notice anything different about my appearance? (if yes, please describe).’’ If they responded negatively to both of these questions, then, consistent with prior work on real-world change detection (e.g., Simons & Levin, 1998), they were considered to have not noticed the change. We then asked them a more specific question: ‘‘Did you notice that I had (did not have) a basketball before the crowd went by and now I don’t (do)?’’ Finally, they were thanked for their participation and debriefed about the purpose of the study. The entire interaction was surreptitiously video and audio taped, and from these recordings, responses were coded later by consensus between the first two authors.

Results and Discussion

As in prior studies of real-world change detection, most observers did not spontaneously report the change to the basketball in response to the first two questions. A total of 3 subjects (27%) across the two conditions clearly noticed the change and reported it in response to one of these questions. Two were in the removal condition and one was in the addition condition. A total of five subjects (45%) missed the change in response to all questions (all were in the addition condition). The most interesting result from this pilot study came from the responses to the direct question about the basketball. In the removal condition, all three participants who failed to report the change in response to the initial questions reported having seen the ball when asked directly. One participant’s response was particularly interesting. After reporting no change to the open-ended questions, when asked about the presence of a basketball, he said ‘‘oh . . . that’s right! So did you pass the ball off to somebody? . . . I didn’t notice that.’’ That is, he reported both having had a representation of the presence of a ball and not noticing the ball’s removal.

Thus, of the participants in the addition condition, five missed the change entirely and one reported noticing it. In the removal condition, two spontaneously noted the absence of the ball, and three reported having seen the basketball only when asked directly (see Table 1). This preliminary finding suggests that observers might show change blindness even when they have a representation of the changed object. Thus, change blindness might result from a failure to compare the initial scene to the changed scene rather than a failure to represent the initial scene.

Because the basketball in this study was a canonical orange color, we could not verify whether participants actually ‘‘discovered’’ their representation of the ball in the removal case or whether they simply responded to the demands of our leading questions. To address this concern and to further explore the intriguing finding that people might have preserved representations of some details of the initial scene even

TABLE 1
Percentage of Participants Reporting the Change in Each Experiment

	Missed change entirely	Spontaneously reported	Reported only when cued
Experiment 1			
Addition ($n = 6$)	83%	17%	0%
Removal ($n = 5$)	0%	40%	60%
Experiment 2[a]			
Addition ($n = 13$)	15%	8%	77%
Removal ($n = 13$)	8%	31%	62%
Experiment 3			
Consistent ($n = 23$)	39%	26%	35%
Inconsistent ($n = 26$)	31%	15%	54%

[a] Experiment 2 included a no-change condition and a false alarm question. In the no-change condition all participants correctly answered all questions about the presence or absence of a basketball. One participant in each condition (addition, removal, and no-change) incorrectly responded to the false alarm question.

when they fail to detect changes, Experiment 2 used an unusual basketball and assessed whether observers responses were affected by our leading questions.

EXPERIMENT 2

Experiment 1 confirmed that the object change was noticeable by some participants and that the passing group served as a sufficient disruption to allow the surreptitious addition or removal of a basketball. More importantly, participants who failed to report the change in response to any of the more open-ended questions sometimes reacted as if they remembered having seen the basketball when it had been removed. In this experiment, we replaced the typical orange ball with an unusual red and white striped ball. This change allowed us to ask, in the removal case, whether or not observers remembered any details of the ball. Furthermore, we added trials on which the ball was present or absent throughout, and an additional question about a change that never occurred, in order to test for any tendency to succumb to demand characteristics in responding to our questions.

The primary goal of this experiment was to explore whether or not, despite exhibiting change blindness, observers maintain a representation of some details of the initial scene. That is, can change blindness occur even when observers do have an explicitly available representation? If observers can recall the properties of the ball, change blindness could result from a failure to compare that representation to the post-change scene. If, on the other hand, they cannot recall whether or not a ball had been present, then change blindness might well be due to a representation failure. Note, of course, that such a finding would be ambiguous in that the measure might not be sufficiently sensitive. Similarly, if pedestrians remembered the presence of the ball but could not describe its details, then we cannot determine whether or not they truly represented the details.

Participants

Forty-five pedestrians provided directions and then answered our experimental questions. Data from 7 participants were eliminated for the following reasons: procedural error resulting in the change itself being visible or in some questions not being asked properly ($n = 3$), unclear responses or an inability of the subject to understand the questions ($n = 3$), familiarity with previous real-world change blindness studies ($n = 1$). A few (uncounted) additional pedestrians either declined to provide directions when approached or declined to answer our questions after the interaction was completed. Thus, the final data set used for analysis included 38 participants. As in Experiment 1, participants were thanked for their assistance and were thoroughly debriefed, but were not otherwise compensated.

Materials and Procedure

Except as noted, the procedure in this experiment was identical to that of Experiment 1. A different female undergraduate served as the assistant in this experiment; she was dressed comparably to the original experimenter. As noted above, this experiment used a red and white striped basketball rather than a typical orange one. Participants were sequentially assigned to one of three conditions: basketball removal ($n = 13$), basketball addition ($n = 13$), and no-change ($n = 12$). In half of the no-change trials, the assistant held the basketball throughout the trial and for the other half, she never had the ball. These trials served as a control to verify that demand characteristics did not lead to false reports of a change or of the prior presence of a ball. As a further control for false alarms to our questions, the assistant wore a white baseball cap during the addition trials and did not wear the hat during the removal trials (she wore the hat for all no-change trials on which she was also holding the basketball). Thus, whenever the ball was present after the crowd went past, the assistant also was wearing a hat, and when the ball was absent, she was not wearing a hat. The presence or absence of the hat never changed during a given trial, so any incorrect responses about the hat could indicate a bias, or compliance with our leading questions.

The sequence of questions was modified slightly as well to explore whether observers represented the features of the changed object. After the participant finished providing directions, the assistant asked three open-ended questions: (1) ‘‘Did you notice anything unusual happen as the crowd of people passed between us? (if yes, please describe),’’ (2) ‘‘Did you notice anything change? (if yes, please describe),’’ (3) ‘‘Do you think anything has changed about my appearance since the crowd went by? (if yes, please describe).’’ If the participant did not report the change in response to these questions, the assistant then asked: ‘‘Do you think that I had a basketball before the crowd went by?’’ In the removal condition or the no-change condition without a ball, if participants responded ‘‘yes’’ to this question, they were asked to describe the ball. In the other two conditions, the ball was still present, so there was no reason to ask them for a description. Finally, participants were asked ‘‘Do you think I had a hat on before the crowd went by?’’ Again, if participants responded ‘‘yes’’ in the removal or no-change condition without a hat, they were asked to provide a description. After they had answered all of the questions, they were thanked for their participation and were debriefed about the purpose of the study. The entire experiment was surreptitiously videotaped, but audio recording was unreliable due to radio interference with the wireless microphone. Consequently, responses to each question were transcribed by the first author during each interaction and verified immediately after each subject in consultation with the assistant who asked the questions.

Results and Discussion

As in prior studies of real-world change detection, relatively few participants spontaneously reported the change to the basketball. In fact, only four subjects (31%) spontaneously reported the removal of the basketball and one subject (8%) reported the addition of the ball (see Table 1), $\chi^2_{(1)} = 2.23$, $p = .135$, a nonsignificant difference. All of the subjects in the no-change conditions accurately reported the presence or absence of the ball (i.e., they reported no ball when none had been present and they reported the ball when it had been present), and only one of these participants (8%) falsely reported a change to the hat. Thus, participants generally did not false alarm in response to our direct questions. Only two participants (15%) in the addition condition failed to report the previous absence of the ball at any point during the questioning, and only one participant (8%) in the removal condition failed to report the previous presence of the ball at any point during the questioning ($\chi^2_{(1)} = .377$, $p = .539$), again a nonsignificant difference. Only one participant in each change condition false alarmed to the hat question. The remaining participants—ten in the addition condition (77%) and eight in the removal condition (62%)—initially failed to report the change, but when asked specifically about the basketball, reported the difference, $\chi^2_{(1)} = 722$, $p = .395$, another nonsignificant difference between conditions.

The critical question in this experiment was whether or not participants who did not spontaneously report the change actually represented the properties of the changed object. According to the strong form of the overwriting hypothesis, observers should be unable to report details specific to the pre-change scene when they fail to detect a change. Evidence for preserved information suggests that change blindness resulted from a failure to compare the representation of the pre-change scene to the post-change scene. The data in this experiment provide strong support for a comparison failure, with more than half of the participants in each condition providing evidence for the existence of a representation despite exhibiting change blindness (with no significant differences between the two conditions).[4] In the removal condition, all of these participants gave descriptions of the ball that mentioned at least one feature that distinguished it from a normal basketball, giving evidence that they remembered the specific ball used in the experiment. Most participants (69% across the two change conditions) were able to ‘‘discover’’ memory for the initial presence or absence of the ball, suggesting that change blindness typically did not result from a failure to

[4] As noted earlier, evidence for a preserved representation is not necessarily inconsistent with a weaker form of the overwriting hypothesis. Overwriting of the representation needed for change perception could still explain why observers were unable to detect the change at the moment it happened. They might still have a different representation that could allow subsequent ‘‘discovered’’ memories. However, this representation should be sufficient for change detection via inference. Consequently, evidence for a preserved representation still supports the claim that change blindness results at least in part from a comparison failure.

represent the initial state of the ball.[5] Not only do we appear to represent information from a changed scene, but that information is potentially accessible to awareness.

EXPERIMENT 3

Given the theoretical significance of the findings of Experiment 2 for the interpretation of change blindness results, an additional experiment was conducted to replicate and attempt to extend this primary finding. Given that the addition/removal manipulation in Experiments 1 and 2 produced no differences in overall change detection, this experiment focused exclusively on the removal condition because it provides more reliable information about discovered memories (because we can verify the precision of the representation). This experiment also used two different removal objects, a soccer ball and a stuffed bunny.

The central additional manipulation in this experiment involved the context in which the change occurred. A second assistant accompanied the person asking directions, and this second person was holding objects that were either consistent or inconsistent with the target object. For example, in one condition, the context assistant was holding a pair of cleats and had an icepack on one arm. That context would be consistent with a person holding a soccer ball and asking directions to the hospital to help treat an arm injured in a soccer game. However, it would be less consistent with a person holding a stuffed bunny and asking directions to the hospital. In contrast, if the context assistant were holding a plant with a ‘‘get well’’ sign on it, then the stuffed bunny might be consistent but a soccer ball would not. The goal of this context manipulation was to explore whether a change to an inconsistent object would be more noticed than a change to a consistent object. And, more importantly, if people did not see the change, would they be more likely to remember the details of an inconsistent object? The existing literature provides conflicting evidence on the role of scene consistency in perception and memory, with some studies supporting better processing of consistent objects (e.g., Biederman, Mezzanotte, & Rabinowitz, 1982; Brewer & Treyens, 1981) and others supporting better detection of inconsistent objects (e.g., Hollingworth & Henderson, 1998; Pezdek, Whetstone, Reynolds, Askari, & Dougherty, 1989). Here we sought to verify whether or not context affects change detection in a real-world interaction.

Participants

Fifty-two pedestrians provided directions and then answered our experimental questions. Data from 3 participants were excluded due to procedural errors resulting either in the change itself being visible or in some questions not being asked. A few (uncounted) additional pedestrians either declined to provide directions when approached or declined to answer our questions after the interaction was completed. Thus, the final data set used for analysis included 49 participants. As in Experiments

[5] In both conditions, the person who false alarmed to the hat question initially failed to report the change but then did report it when asked directly. In the removal condition, this person gave a ‘‘close’’ description of the ball, suggesting that they did have a representation of the specific ball used in the study.

1 and 2, participants were thanked for their assistance and were thoroughly debriefed, but were not otherwise compensated.

Materials and Procedure

Except as noted, the procedure in this experiment was identical to that of Experiment 2. Two female undergraduates served as the *primary assistant* and the *context assistant* in this experiment. Both were dressed in clothing that could be consistent with a casual soccer game, although their clothing would not have been unusual in other settings. The primary assistant and the context assistant approached a pedestrian to ask for directions to the university hospital. The primary assistant controlled the interaction and did all of the talking. The context assistant casually tried to look at the primary assistant throughout the interaction in order to direct the pedestrian's attention to the primary assistant. Pedestrians were sequentially assigned to one of two context conditions: (a) context assistant dressed as an injured soccer player holding an icepack and a pair of cleats (*player context*), or (b) context assistant dressed as a hospital visitor holding a plant (*visitor context*). These two contexts were crossed with a consistency manipulation defined by the changing object. In one case, the object was a soccer ball and in the other case it was a stuffed bunny holding a ‘‘get well’’ sign. The ball was consistent with the player context and inconsistent with the visitor context. The bunny was consistent with the visitor context and inconsistent with the player context. Thus, participants were sequentially assigned to each of the 2 (context) $\times$ 2 (consistency) conditions. A total of 23 participants were included in the two consistent conditions and 26 were included in the two inconsistent conditions.

Given these changes to the procedure, the questions asked after the pedestrian finished giving directions were changed somewhat. The primary assistant first asked two open-ended questions: (1) ‘‘Did you notice anything unexpected happen when that group of people walked by us? (if yes, please describe),’’ (2) ‘‘Did you notice anything change when they walked by us? (if yes, please describe).’’ If the participant did not report the change in response to these questions, the assistant then asked two more focused questions: ‘‘Do you think I was carrying anything before they walked by us? (if yes, please describe).’’ When the assistant asked this question, she directed attention to her arm and pretended to be holding an object as she would have been if the object were still present. Thus, subjects had both a verbal and a visual retrieval cue. Finally, if the observer did not report the target object in response to this question, the assistant asked: ‘‘Do you think I was carrying a ball (stuffed animal) before they walked by us? (if yes, please describe).’’ Unlike the questions in Experiments 1 and 2, this question was ambiguous about the type of ball or the type of stuffed animal. Thus, successful identification of the type of object would indicate a more complete representation. Given the small number of false alarms in Experiment 2, this experiment eliminated the no-change conditions and the hat question. Unlike Experiments 1 and 2, this experiment was not video or audio taped. Instead, the context assistant recorded the response to each question on pre-printed response cards, and responses were coded immediately by the first author in consultation with the two assistants.

Results and Discussion

In order to more fully analyze the effect of consistency in these experiments, we combined data from the two consistent conditions (visitor context with the bunny and player context with the ball) and the two inconsistent contexts (visitor with the ball and player with the bunny). As in the previous studies, many pedestrians did not report the change in response to the open-ended questions (questions 1 and 2). A total of six participants (26%) spontaneously reported the change in the consistent context and four participants (15%) reported the change in the inconsistent context. The difference in noticing rates was not significant, $\chi^2_{(1)} = .860$, $p = .354$. A slightly greater percentage of subjects failed to report the change in response to all of the questions than in previous experiments: nine participants (39%) in the consistent condition and 8 participants (31%) in the inconsistent condition. Again, the difference between these conditions was not significant, $\chi^2_{(1)} = .376$, $p = .539$. Finally, many participants failed to report the change in response to the open-ended questions, but successfully reported the change when asked more leading questions: eight participants (35%) in the consistent condition and 14 participants (54%) in the inconsistent condition, $\chi^2_{(1)} = 1.79$, $p = .180$, a nonsignificant difference. Of these participants, 6 out of 8 in the consistent condition gave good descriptions of the target object and 2 gave less precise descriptions (e.g., describing the ball as a volleyball or describing the bunny as brown rather than white). In the inconsistent condition, 9 out of 14 gave precise descriptions and 5 gave less precise descriptions.

Thus, across both consistent and inconsistent conditions, 10 participants (20%) spontaneously reported the change, 17 participants (35%) never reported the change, and 22 participants (45%) discovered memory for the removed object when asked leading questions. Of these 22, 15 gave descriptions that revealed encoding of some details of the changed object even though they were change blind. The consistency manipulation had relatively little effect, with no significant differences between conditions. The lack of a difference between the consistent and inconsistent context conditions is concordant with recent findings from studies of video-based change detection (Angelone et al., 2001). In those studies, a similar manipulation of consistency also produced no reliable differences.

In sum, this pattern of results is consistent with the claim that change blindness for unexpected changes can result from the failure to compare an existing representation to the current scene. That is, most observers do not spontaneously compare one scene to the next, but with probing questions many of them ‘‘discover’’ their memory of the changed object.

GENERAL DISCUSSION

Across three experiments, many participants who failed to report a change in response to open-ended questions successfully discovered a memory for the initial, pre-change scene when asked specific questions about the changed object. Furthermore, in Experiments 2 and 3 they were usually able to report sufficient detail for us to verify that they had represented the pre-change object. These findings are consistent with the conclusion that change blindness sometimes results from a failure to compare existing representations. Note that observers often expressed surprise at their recall of the original object, even explicitly commenting that they had not noticed the change itself. Other cases of change blindness in these studies might well result from a representation failure. For example, in Experiment 3, a substantial minority of participants were unable to ‘‘discover’’ any memory for the removed object. These participants may not have formed or retained a consciously accessible representation of that object. However, the finding that some observers appear change blind even when they are subsequently able to recall some details provides a strong argument against the use of change blindness to infer minimal representations of scenes. This finding provides an existence proof that change blindness can occur even if observers have represented sufficient information to infer the presence of a change. Whether or not such comparison failures occur in other change detection tasks, particularly intentional tasks, should be investigated. Although overwriting likely plays a role in change blindness, our findings suggest that other mechanisms might contribute as well.

These studies demonstrate that change blindness might well occur despite the presence of a representation that would, in principle, be sufficiently rich to support change detection. Why, then, do participants fail to detect changes? One plausible explanation focuses on the purpose of representing visual details from scenes. Assume that the primary goals of scene perception are to understand the meaning of the scene and to assess the potential for action in the scene. When pedestrians first encounter the assistant, they might encode the meaning of the scene as ‘‘an athletic person asking for directions.’’ That semantic encoding does not change when the ball (or animal) is removed. Consequently, observers do not spontaneously update their representation to account for the change. Rather, they rely on their initial encoding of the meaning of the scene even when it is inconsistent with the current state of the scene.

Many models of object recognition (e.g., object file theory) presuppose an automatic updating mechanism that adjusts representations of attended objects as they move or change (e.g., Kahneman, Treisman, & Gibbs, 1992; Treisman, 1993). For example, object files supposedly allow accurate change detection for attended objects by constantly updating the representation. The only way in which such a mechanism could fail to detect change would be for the updates to overwrite the initial representation. Yet, these real-world studies demonstrate that change blindness could occur even without overwriting. Consequently, they suggest that the assumption of automatic updating might not apply to real-world perception. Alternatively, updating might be limited only to attended objects in a scene, and the changing object might not have been attended throughout the task. However, even when a central attended object in a scene is changed, observers often fail to notice (Levin & Simons, 1997; Simons, 1996; Simons & Levin, 1998). In a sense, it would be a waste of effort to constantly encode all the visual details of attended objects with each view.

Given the assumption that a primary goal of perception is to extract the meaning of a scene, observers might initially encode enough features to arrive at that meaning. Thereafter, they might rely on their assessment of the meaning or gist rather than on the visual details. That is, they have a representation of the details of the scene that was used to arrive at the meaning, but once they understand the meaning, they need not refer to those details. Provided that the meaning remains constant, observers generally will not notice changes to the details of a scene. To verify that the meaning is constant, observers need not re-encode all of the details of a scene with each view. Rather, they simply need to check a few features to make sure they are in the same scene. This view of scene perception is consistent with the notion that people rely on existing scene schemas to simplify the task of encoding and remembering scenes (e.g., Friedman, 1979; Neisser, 1976). By identifying the scene's meaning, they can avoid the need to encode and update all the details related to that schema from one view to the next.

This explanation for change blindness and visual stability makes several interesting predictions. First, it predicts that representations of the initial view of a changed scene might contain some detail even if we lack any representation of the changed view. This prediction runs counter to claims of overwriting as the mechanism for change blindness, arguing instead for ''first impressions'' as the basis for scene representations. Accordingly, if it were possible to change many details of a scene without changing its meaning, observers might be change blind and still have better memory for the initial state of the scene (e.g., see Friedman, 1979, for discussion). Of course, the more details that change, the more likely observers will be to detect a change, particularly if they are looking for changes. However, this model of stability suggests that observers might check relatively few features of the scene with each glance, particularly if they are not actively looking for changes. Similarly, this explanation predicts that observers will be more likely to detect changes that affect the meaning of a scene than those that do not affect the meaning. If a change affects the meaning of a scene, observers will be more likely to compare the details of the scene to their representations and thereby detect the change. The meaning serves as a trigger for spontaneous detection of unexpected changes. Evidence from intentional change detection tasks also suggests that we successfully compare relatively few features from each view of a scene (Rensink, 2000c). Consequently, these arguments might generalize to cases in which observers actively search for change. Evidence that observers are better able to detect changes to objects that are the ''center of interest'' in a scene (Rensink et al., 1997) provides some preliminary support for this position.

The findings of our experiments and the claim that more is represented than we might expect based on overwriting explanations for change blindness are both consistent with recent claims for implicit representations in the face of change blindness. Several studies report evidence suggesting implicit detection of changes in the absence of explicit awareness of change (e.g., Fernandez-Duque & Thornton, 2000; Henderson & Hollingworth, 1999; Smilek, Eastwood, & Merikle, 2000; Thornton & Fernandez-Duque, 2000; but see Mitroff & Simons, in press; Mitroff & Simons, 2000, for evidence that most if not all of these claims can be explained by explicit contamination). The conclusion from our studies and from these attempts to find implicit change detection are similar. Both purport to show that more is represented than change blindness might initially lead us to believe. However, claims for implicit change detection require more than just a representation of the pre-change scene: they also require a comparison to the post-change scene that occurs without awareness. In our view, there is no evidence to support such an implicit comparison process (Mitroff & Simons, in press; Mitroff & Simons, 2000), hence, there is no strong support for implicit change detection. However, even without implicit change detection, there could still be implicit representations that are not compared from one view to the next. The studies presented here demonstrate the existence of *explicitly* available representations, so it seems entirely plausible that some aspects of a scene might be implicitly represented as well (e.g., Chun & Jiang, 1998). In a sense, the representations of the details of the changed objects in our experiments were implicit until the retrieval cue made them explicit; subjects were unaware that they had the representations until they were appropriately cued.

Regardless of whether the representation of the pre-change scene is implicit or explicit, the existence of such a representation need not imply that that representation is used to detect changes. Although an explicitly available representation presumably could be used to infer the existence of a change, it might not support change perception. That is, the form of the preserved information might not be compatible with the ability to spontaneously detect the presence of a change. At least in the case of unexpected, real-world changes, most change detection likely occurs through a process of inference rather than perception (Simons & Mitroff, 2001). Consequently, any evidence for preserved information in the face of change blindness under these conditions provides fairly strong support for a comparison failure. However, intentional change detection tasks often allow for the possibility of change perception in addition to change inference. The preserved representations uncovered by our studies might not support detection via perception. If not, then overwriting might well be the most viable explanation for such failures. Our studies do raise the possibility, though, that more is represented even in intentional tasks than the strong form of overwriting implies. Further research is needed to uncover the nature and specificity of the representations underlying successful change detection, both via perception and via inference. Such research could clarify whether the same sorts of representations underlie both processes.

Our findings are, on their surface, somewhat inconsistent with some of our other studies of real-world change detection (Levin et al., in press). In those studies, pedestrians encountered a person-change while providing directions (or while taking a photograph of the experimenter). After the change, they were shown a photographic lineup and were asked to pick the pre-change person from the lineup. Observers who successfully detected the change were able to do so better than chance, but those who missed the change were substantially worse and were not better than expected by chance. Although this finding might be taken to imply the absence of a representation of the pre-change stimulus, that conclusion would be premature. Observers might well have represented some details of the pre-change stimulus, but if all of the items in the lineup were roughly consistent with the details they did represent, then they would not be able to select the target item from the lineup. For example, even if observers encoded the presence of an anomalous basketball, they might not be able to recognize which of several different anomalous balls had been present. In our recall task, their descriptions of the ball (or stuffed animal) were sufficiently detailed to determine that they had some representation of the unusual features. Hence, the criterion for successful representation in our task might have been more lenient, even though the task required cued recall rather than recognition. Further research with photographic lineups is needed to determine the level of detail in the preserved representations.

The results of our studies are entirely consistent with recent evidence from video-based change detection (Angelone et al., 2001). Observers who miss an unexpected change are just as likely as those who detect the change to pick the pre-change properties or person from a photographic lineup. Such findings suggest that overwriting does not entirely account for change blindness; even if observers have represented the pre-change features, they might not detect a change. These videos used changes similar to those we used in the current studies: a basketball was replaced or a jersey changed colors. Consequently, the lineup showed objects with different features. If observers maintained a representation of some details of the objects, they might well be able to use their memory to select the right photograph better than chance, thereby revealing the presence of their representation. Future studies could use this technique to assess how much of a scene observers represent and in how much detail they represent it. Together, the current studies and these video studies suggest that, at least for some types of changes (e.g., unexpected changes in natural scenes), change blindness can result from the failure to compare an existing representation to the post-change scene.

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