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Memory for centrally attended changing objects in an incidental real-world change detection paradigm

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People often have difficulty detecting visual changes in scenes, a phenomenon referred to as 'change blindness'. Although change blindness is usually observed in pictures of objects that are not the focus of attention, it also occurs for attended objects in the real world. Here, we further explore the finding that many participants fail to detect the unexpected substitution of one conversation partner for another. We show that change blindness for a conversation partner occurs in a variety of situations. Furthermore, when tested with a photographic lineup following the change, participants who noticed the substitution showed better memory for both pre- and post-change experimenters than participants who did not detect the change. We conclude that change blindness in this case is associated with relatively ineffective or inaccessible representations of previously attended objects, and we contrast these results with others indicating that change blindness arises from a failure to compare the original and changed object.

A wide variety of studies demonstrating 'change blindness', or the inability to detect changes in visual scenes, emphasize the contrast between the richness of perception and the sparseness of representation (Blackmore, Brelstaff, Nelson, & Troscianko, 1995; Grimes, 1996; Henderson, 1997; Levin & Simons, 1997; McConkie & Currie, 1996; O'Regan, Deubel, Clark, & Rensink, 2000; Pashler, 1988; Phillips, 1974; Rensink, O'Regan, & Clark, 1997; Simons, 1996; Simons & Levin, 1998; for a review, see Simons & Levin, 1997). Although research has consistently revealed the visual system's impressive ability to analyse scenes, segregate figures from backgrounds, and quickly categorize objects, findings of change blindness suggest strict limits on the amount of information that can be consciously retained and compared from view to view, even

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over short delays. These data justify the conclusion that successful change detection, whether in complex natural scenes or simple arrays of objects, requires attention to be focused on the changing object (Rensink, O'Regan, & Clark, 1997). However, even if attending to an object may be necessary for change detection, it is not sufficient — even changes to attended objects can go undetected. For example, two-thirds of participants miss the substitution of one actor for another in short videos (Levin & Simons, 1997), and about half miss the substitution of one conversation partner for another in a real world interaction (Simons & Levin, 1998). Thus, research on change blindness not only emphasizes the role of attention in selecting objects for further processing but also demonstrates that only some aspects of attended objects are consciously retained and compared across views. Here, we test for change blindness in real-world attended objects using a number of different scenarios, and test the degree to which change detection is associated with consciously accessible representations of the changed features.

Change blindness for attended objects

Intuitively, most people think that they would detect unexpected visual changes, especially those that occur within the focus of attention (Levin, Drivdahl, Momen, & Beck, submitted; Levin, Momen, Drivdahl, & Simons, 2000). Although this intuition is strong, it is often incorrect. For example, in one study, participants viewed short videos in which a variety of unexpected visual changes occurred across cuts (Levin & Simons, 1997). In one case, an experimenter stood up to answer a phone and was replaced by a different actor across a change in camera angle, and in another, a person's clothing changed repeatedly during a conversation. Participants viewing feature changes almost never noticed them, and even when we changed the central actor in a video, on average, two-thirds of participants did not notice the switch (Levin & Simons, 1997). Such change blindness even extends to real-world changes. In one experiment, a first experimenter approached participants on a university campus and asked them for directions to a nearby building. While they were conversing, two other experimenters carrying a wooden door stepped between the participants and the first experimenter, momentarily obscuring the participants' view of all three experimenters. During the interruption, one of the experimenters carrying out the door stayed behind to continue the conversation as the first grabbed the door and walked away behind it (Simons & Levin, 1998). Surprisingly, approximately 50%of participants failed to detect this change and continued the conversation as if nothing had happened. Thus, a change to an attended object (the participant's conversation partner) escaped notice, showing that attending to an object does not guarantee change detection, even if the change is dramatic and occurs during a relatively brief disruption. This implies that people do not automatically retain and compare visual details across views needed to consciously detect change — to successfully detect change, it is necessary to attend to, and explicitly encode, the specific features that are different between the pre-and post-change objects (O'Regan, Deubel, Clark, & Rensink, 2000; Simons & Levin, 1998).

Although this experiment (Simons & Levin, 1998) provides a dramatic example of change blindness for attended objects in the real world, the magnitude of the effect may be partly attributable to the nature of the task itself. First, participants were performing a complex visual/spatial task both before and after (and perhaps during) the change — giving directions to the experimenter. In so doing,they often alternated between looking at the experimenter and looking where they were directing the experimenter to go. In addition, participants may have focused on the map held by the experimenter, which may have further distracted them. Perhaps more importantly, the disruption used to enact the change was unnatural—two people carrying a door wedged themselves between the participant and experimenter, which many participants obviously found a bit surprising.

More generally, however, failure to detect the change could be due to a variety of representational or process failures (see Simons, 2000 for a more detailed discussion). First, participants may fail to represent sufficient visual information about the pre- or post-change objects (or both) to allow change detection. Alternatively, their representation of the objects may be sufficiently detailed, but not consciously accessible. That is, the representations may either be too weak or poorly organized to retrieve, or they may be implicit rather than explicit. Both of these possibilities involve the absence of a consciously accessible representation. Second, participants may have effectively represented the pre- and post-change objects, but nonetheless miss the change because they fail to compare those representations across views. Based on this hypothesis, the process of representing and that of comparing across views are independent. Accordingly, a failure could occur in either or both. The important prediction for present purposes is that the representational failure hypothesis predicts that participants who miss the change should be less able to consciously access representations of the changing object than participants who detect the change. The no-comparison hypothesis predicts no differences in the level of detail in the representations of those who do and do not detect the change. Of course, it is possible that an incomplete representation can interfere with the comparison process, especially if the representation does not allow adequate alignment of features on the pre- and postchange objects (e.g. a failure to compare features with their analogous counterpart on the postchange object; see Markman & Genter, 1997), but in this case, we would argue that the representational failure is the ultimate cause, because it underlies the comparison failure. Accordingly, we are testing a comparatively pure version of the comparison failure hypothesis, which assumes no difference in the amount of represented detail, or its accessibility, between participants who do and do not detect the change.

Our goals here were to replicate the original door study (Simons & Levin, 1998), using less intrusive methods of substituting one conversation partner for another, and to explore the relationship between change blindness and the level of consciously accessible detail in participants' representations by determining the degree to which participants who do and do not see the change can identify the experimenters in a lineup. If change blindness results from a failure to represent information about the actors, participants who miss the change should have difficulty selecting the changed person from a lineup. However, if change blindness results from a failure to compare two representations, performance in selecting the experimenter from a lineup should be comparable for those who did and did not detect the change.

In Expt. 1, we performed a person switch in which one experimenter ducked behind a counter and a different experimenter stood up. That is, the task did not involve an unnatural disruption or unexpected distraction. In Expt. 2, we added a lineup to the original door paradigm to test the degree to which participants could identify the initial experimenter whether or not they noticed the change. Furthermore, in addition to the original task of giving directions, we also used a new task in which a passer-by was asked to take a photograph of the experimenter. In this case, the change occurred while the participant was composing the photograph. Again, this new task involves less distraction and disruption than the original door event. Expt. 3 replicated Expt. 2 with separate lineups for both the first and second experimenter.

EXPERIMENT 1

Here, we switched one conversation partner for another using a new scenario. The participant approached a counter to participate in an experiment. The participant signed a consent form and then handed it to a first experimenter, who then ducked behind the counter to put it away. A second experimenter then stood up, replacing the first experimenter. Consequently, observers were not performing a distraction task (e.g. giving directions), and there was no unusual visual disruption or distracting event (e.g. a door). Our goal in this study was to determine whether change blindness would ensue in the absence of such distractions and with a more natural transition between experimenters.

Method

Participants

A total of 21 undergraduates at Harvard University completed the experiment in exchange for candy. Data from one participant were eliminated, because he was tall enough to see the second experimenter while talking to the first experimenter.

Stimuli and procedure

Two caucasian male undergraduates served as the experimenters who executed the switch. Both actors wore a white button-down shirt and a bolo tie. Thus, their overall appearance was similar. However, they had differently coloured and styled hair (one brown and straight, one blond and curly with sideburns), distinct facial features, and distinct voices.

Participants were recruited from the lobby of the psychology building. They were told that they could participate in a 5–10 min study in exchange for candy, but were otherwise unaware of the purpose of the study. They were directed to the 8th floor of the building, where they were met by an assistant who directed them to the counter. An 'Experiment Here' sign hung above the counter, and the first experimenter stood behind the counter and was visible to the participants when they approached. Each actor served as the first experimenter for half of the participants. The counter was 106 cm high and 71 cm deep, so it completely blocked from view the second experimenter who was kneeling behind it. As the participant approached the counter, the first experimenter asked 'Are you here for the candy study?' The participant was then asked to read and complete a consent form. The form stated that 'you will view a brief event and then we will ask a series of questions about it'. After the participant signed the consent form, the first experimenter took it and ducked behind the counter while saying 'let me just get you these forms'. Once the first experimenter was completely hidden from view, the second experimenter rose from behind the counter in the same position where the first experimenter had been and handed the participant a packet of questions. The second experimenter then directed the participant through a doorway where they were met by an assistant and led to a small room to provide written answers to a series of questions about what they had just seen.

Each question was printed on a separate page of a packet, and participants could not see or change their answers once they had turned a page. First, they were asked to describe everything that had happened since exiting the lift on to the floor with the experiment. Second, they were asked 'did you notice anything unusual while you were at the counter? (If yes, please describe.)' Depending on whether or not they reported noticing the change in their responses to these questions, they were given new packets with additional questions. If they missed the change, they were asked to respond to the following two items, each on a separate page of a packet: (1) 'Please describe any notable features of the person at the counter'. (2) 'Did you notice anything change about the person behind the counter after you signed the consent form? (If yes, please describe.)' If they noticed the change, they responded to the following sequence of items: (1) 'Please list any notable features that were *the same* for both experimenters at the counter'. (2) 'Please list any notable features that *differed* between the two experimenters at the counter'. (3) 'When you suspected there was a change, did you consider pointing it out?' Finally, all participants were given a brief written description of what had happened and were asked if they had ever seen the experimenters prior to the study and whether they had heard about this type of research before (and if so, where). Upon completing all of the relevant questions, participants were thoroughly debriefed and were informed that change blindness was common for this sort of change. A video depicting a simulation of the event and images and the experimenters are available at the following website: www.wjh.harvard.edu/~viscog/lab.

Results and discussion

Of the 20 participants who experienced the change without being able to see both experimenters simultaneously, 75% (15 out of 20) failed to detect it. Although these participants reported many details of the experimental situation in their descriptions, they did not report any changes either time they were asked. The 25% (5 out of 20) who did notice the change typically reported it the first time they were asked, noting a difference in the voices, facial features, hair colour, or hair styles of the actors (several participants mistakenly reported differences that did not exist, e.g. that one experimenter had glasses or that the two wore different-coloured clothing).

Interestingly, having heard about person-change studies in the past appeared to have no impact on the likelihood of change detection. Nine of the 20 participants had heard about or seen videos of the door studies described earlier (Simons & Levin, 1998). Of these nine participants, six did not notice the change. In fact, six of these nine participants were inadvertently recruited for our study just after they had left a meeting for potential psychology majors. In that meeting, the speaker had described the original person-change study (Simon & Levin, 1998) in detail as an example of how findings in psychology are often counter-intuitive and surprising. Consequently, these students participated in our experiment within 1 h of hearing about the door study, and four out of six still did not notice the change. One of them commented 'I thought I would notice something like that, but I didn't. Curious'. Another commented 'I didn't think I would fall for something like that...' These comments emphasize the magnitude of the metacognitive error of change blindness: even after people have been told that under the right conditions, people will not notice if their conversation partner is swapped, they still hold the intuition that *they* would notice the change (Levin, Drivdahl, Momen, & Beck, submitted; Levin, Momen, Drivdahl, & Simons, 2000). Furthermore, this finding suggests that knowledge about one type of person change does not inoculate participants to other comparable changes, provided that the change occurs in a different setting.

As in earlier studies in which the change occurred as a door passed between the participant and the experimenters (Simons & Levin, 1998), a significant proportion of participants did not detect the person-switch. Accordingly, change blindness cannot be attributed solely to the nature of the event or to the disruption caused by the door. In this experiment, participants often missed the change, even when there was no unnatural disruption. In fact, the level of change blindness in this experiment was somewhat greater than in earlier studies using the door event, perhaps owing to the smoothness of the transition and the participant's relative comfort with the situation[1]. In the door studies, participants were approached by the experimenter and did not realize they were in an experiment until after the change had happened. However, in this 'counter' variant, observers were volunteering to participate in an experiment and still missed the change.

EXPERIMENT 2

Here, we exchanged a first conversation partner for a second using two different scenarios. The first was similar to the door event used by Simons and Levin (1998). A first experimenter approached the participants and asked for directions to a building on campus. As the two talked, two other experimenters carrying a door interrupted the conversation, and one of the experimenters carrying the door switched with the first experimenter. In the second scenario, a first experimenter approached the participant and asked if he/she would be willing to photograph the experimenter in front of a wall display. While the participant was composing the photograph, the disruption and substitution occurred.

The primary goal of this experiment was to determine whether participants would be able to identify the first experimenter in a lineup. When the switch was completed, participants were first questioned about whether they had seen the change, and then they were asked to pick the first experimenter out of a four-person photographic lineup. If a representational failure causes change blindness, we would expect that participants who miss the change would be worse on the lineup than those who detect the change.

Method

Participants

A total of 75 participants completed the experiment. Of these, 36 were in the door condition (19 female, mean age = 24.5), and 39 were in the photo condition (19 female, mean age = 22.2).

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[1] Another explanation for the relatively low levels of noticing in this experiment is that the two experimenters were dressed identically. However, even when a new group of participants viewed an identical event, but with the experimenters wearing different coloured shirts, only 2 out of 7 noticed the change. This level of noticing is comparable with that when the participants wore identical clothing. Also, this finding is consistent with evidence from the door studies that many participants failed to notice the change, even when the two experimenters wore different coloured clothing (bright blue vs. black).

Stimuli

For all trials, the switch was between two male experimenters. They wore similar but visibly different clothes: one wore a blue plaid shirt, a white baseball cap, and a neck chain, and the other wore a green plaid shirt, a tan baseball cap, and no jewellery. Each served as the first experimenter for approximately half of the participants.

Four, 4-item (1 target, 3 distracters) lineups were created, 2 with each experimenter as the target. The lineups for each experimenter used different distracters, chosen to ensure that the mean related similarity between the target and distracters (seven judges' ratings produces a mean of 3.50 on a 7-point scale with 1 as 'very similar') was approximately equivalent to the similarities between each distracter and the other items in the lineup (mean of 3.75). The two lineups for a given experimenter were the same, except that the positions of the four items were rearranged.

Procedure

In the directions scenario (modelled after Simons & Levin, 1998), participants were approached by a male experimenter carrying a campus map. He asked the participant for directions to the library, which was some distance (and several turns) from their current location. During the conversation, the experimenter and participant were interrupted by two other experimenters carrying a wooden door. As the door was carried between the first experimenter and the participant, one of the male experimenters carrying the door stayed behind to continue the conversation, while the first experimenter left behind the door. In the photo scenario, the first experimenter approached the participant with a disposable camera (note that these cameras have no controls aside from the shutter button) and asked if he/she would be willing to photograph the experimenter in front of a wall display containing a number of awards and citations. While the participant was looking through the camera at the experimenter, two other experimenters carrying a large piece of cardboard walked between the first experimenter and the participant, allowing the first experimenter to leave and the second to stay behind.

In both cases, once the switch was completed, the second experimenter interviewed the participant. First, he asked, 'Did you notice anything unusual during the interaction?' If the participant mentioned the interruption, the experimenter asked if he/she had noticed anything else. If he/she said they had noticed nothing, they were asked if they were sure of that. They were then asked if they had noticed 'anything unusual about the person you have been talking to (photographing)'. If they said yes, they were asked what they had noticed (assuming they did not mention this spontaneously). If participants had not mentioned the person-switch by this time, they were asked, 'Did you notice that I am not the person you were talking to (photographing) before the door (poster) went by?' Upon completing these questions, participants were told they were in an experiment on scene perception, and that it is not unusual for people to miss changes like the change they had experienced. They were then given the lineup and asked if they could select the first experimenter. Finally, all participants were debriefed and given the opportunity to have their data withdrawn (because of the impossibility of obtaining prior informed consent in this paradigm).

Results

Across the two conditions, 45% of participants (34 out of 75) did not spontaneously report noticing the change and, even when asked directly, claimed they had not seen the change. In the directions condition, 38%(15 of 39) of participants missed the change, and in the photo condition, 53%(19 of 36) missed the change ($\chi^2(1) = 1.55$, n.s.). Four participants (two in the door condition and two in the photo condition) reported that they did not notice anything unusual, but then claimed to have seen the person-substitution when asked directly. These participants were classified as having seen the change.

Among those who did not report noticing the change, 26%(9 of 34) correctly picked the target from the lineup. In contrast, 63%(26 of 41) who noticed the change picked the correct person in the lineup. Thus, those who saw the change were more accurate ($\chi^2(1) = 10.19$, $p < .005$) and above chance ($\chi^2(1) = 32.26$, $p < .001$) on the lineup, whereas participants who missed the change performed at chance on the lineup. If participants who reported seeing nothing unusual but claimed to see the change are removed from among those presumed to have noticed the change, the hit rate on the lineup becomes 68%(25 of 37).

Discussion

Experiment 2 replicates the earlier door study (Simons & Levin, 1998) by showing that a significant proportion of participants fail to notice the substitution of their conversation partner. In addition, change blindness was evident in both the photo and directions conditions, again suggesting that the effect is not strictly bound to the demands of the specific scenario. More important, lineup accuracy was poor for participants who missed the change but was significantly greater and above chance for those who noticed the change. This finding suggests that change blindness is associated with poorer memory for the details of the pre-change object.

Although poor lineup performance would be consistent with the hypothesis that change blindness is caused by failure to represent visual details of the first experimenter, it is insufficient to strongly support the claim that observers lack representations altogether. Lineup performance could be poor for a number of reasons. Most obviously, the lineup could simply be too difficult. Although the contrast between experimenters was sufficient to allow change detection by 55% of participants, it is possible that the contrast between the target and distracters for each lineup was smaller, making the lineup discrimination more difficult than the change-detection task. However, the mean rated similarity between the target and the distracters was not markedly different from the similarity of the two targets. Even though the similarity ratings were comparable, the actors in the lineups may still have been more difficult to discriminate, owing to a general lack of perceptual detail. Therefore, it is more productive to focus on the finding that participants who saw the change were considerably more accurate on the lineup than those who did not. This finding suggests that successful change detection is associated with more effective representation of the pre-change experimenter.

In addition, we should emphasize that the representational failure we have documented was revealed by poor lineup performance. Although post-event recognition tests are a common and reasonable means of assessing representations (see, for example, Markman & Gentner, 1997), they measure a specific type of representation (e.g. consciously accessible representations), and they do not specify the exact nature of the representational failure that leads to poor performance. Like all tests of memory, lineups cannot distinguish between poor performance based on not having represented the stimulus initially, and not being able to access a representation that nonetheless does exist. Therefore, for present purposes, the representational failure hypothesis should be considered specific to conscious representations, and to encompass either an encoding or retrieval failure. Although equating retrieval failures with representational failures might be considered arbitrary, representations that cannot be consciously accessed are ineffective for many purposes (especially when the context and perceptual cues provided by a photographic lineup are not sufficient to allow retrieval), and it is legitimate to consider them to have failed in an important way. Of course, we do not intend to imply by this conclusion that implicit representations play no role in perception.

EXPERIMENT 3

Given that successful change detection in Expt. 2 was associated with better performance in selecting the initial experimenter from a lineup, change blindness may result from a failed representation of the initial factor. However, this finding is ambiguous in at least one important way: poor lineup performance could indicate that the appearance of the second experimenter overwrote a representation of the first (see Simons, 2000 for a discussion). If so, participants who missed the change may have represented the features of the pre-change experimenter, but the representation was almost immediately replaced by a representation of the second experimenter. Experiment 3 attempts to disambiguate these hypotheses by testing participants' ability to identify both the pre- and post-change experimenters. If overwriting caused change blindness in Expt. 2, participants who miss the change in Expt. 3 should be poor at identifying the pre-change experimenter but more able to identify the post-change experimenter—the representation of the second experimenter would not have been overwritten. If, however, change blindness resulted from an impoverished representation and not by overwriting, we should expect poor performance on both the pre- and post-change lineups for those who miss the change.

Method

Participants

A total of 67 participants completed the experiment. Three additional participants were approached and complied with our request to take a photograph, but did not want to complete the post-experiment interview.

Stimuli and procedure

The photo scenario from Expt. 2 was used in all trials, and the procedure was identical except for the following variations. Two different pairs of female experimenters were used in this experiment, but the majority of participants saw one of the pairs. The lineups were slightly different from those used in Expt. 2. Again, two different 4-item lineups were created for each experiment, but in this case,the 2 different sets of distracters were both used for each experimenter. As in Expt. 1, pre- and post-change experimenters were counterbalanced, although the lineup for the pre-change experimenter was always given before the lineup for the post-change experimenter.

On each trial, a participant was approached by a first experimenter who was replaced by a second experimenter during the interaction. After the participant took the picture, the second experimenter took the camera back, thanked the participant, and left by walking around a nearby corner. When the second experimenter was out of view, a third experimenter approached the participants, explained that they had just been in a psychology experiment, and asked them if they would be willing to answer some questions about what had happened.

Results

Overall, 19 out of 67 participants (28%) missed the change. Of those who missed the change, 37% correctly identified the target in the pre-change lineup, and 32% were correct for the post-change lineup. Neither of these success rates were significantly above chance ($\chi^2(1) = 1.42$, $p = .233$, and $\chi^2(1) = .44$, $p = .507$, respectively). Of those who saw the change, 81% were correct on the pre-change lineup, and 73% were correct on the post-change lineup. Both of these rates were above chance ($\chi^2(1) = 81.00$, $p < .001$, and $\chi^2(1) = 58.77$, $p < .001$), respectively. For both pre- and post-change lineups, those who saw the change were more accurate than those who did not ($\chi^2(1) = 12.47$, $p < .001$ and $\chi^2(1) = 9.79$, $p < .005$, respectively).

Overall, participants in Expt. 3 showed significantly less change blindness than those in Expt. 2 (45% in Expt. 2 vs. 28% in Expt. 3; $\chi^2(1) = 4.35$, $p = .037$), and they were more accurate on the pre-change lineups (47% in Expt. 2 vs. 69% in Expt. 3; $\chi^2(1) = 6.98$, $p = .008$). Lineup accuracy did not differ significantly between experiments when testing differences among subgroups of those who saw the change and those who missed the change ($\chi^2(1) = 3.57$, $p = .059$, and $\chi^2(1) = .618$, $p = .432$, respectively).

Discussion

In Expt. 3, two findings are of central importance. First, the memory advantage associated with detecting the change was similar for pre-change (44%) and post-change lineups (41%). In addition, the change was reported by a higher proportion of participants in Expt. 3 than in Expt. 2, suggesting that the experimenters were more effectively represented in Expt. 3, perhaps because they were more distinctive or because people are more likely to individuate female experimenters than male experimenters. This increase in change detection was also associated with better performance selecting the first experimenter from a lineup in Expt. 3. Both of these findings suggest that change detection was associated with more effective representations of the changing objects. The comparable performance for pre- and post-change lineups suggests that representational overwriting was not the cause of change blindness. If it were, we would expect better performance on the postchange lineup for participants who missed the change.

Another point to consider is the within-participant relationship between a correct response on the first lineup and a correct response on the second lineup. The overwriting hypothesis suggests that participants retained information about the second experimenter at the expense of the first. A similar alternative is that participants who missed the change represented the first experimenter at the expense of the second (see Simons, 2000 for a discussion). Even though this latter hypothesis is unlikely given the results of both Expts. 1 and 2, the implication of both of these hypotheses is that participants who miss the change should have effectively represented one, but not the other, experimenter. If this were true, we would expect a pattern of results in which the probability of getting one of the two lineups correct would be greater than that expected by chance given the base rates of success for each lineup. This was not the case. Given that participants who missed the change were correct 37% of the time on the pre-change lineup and 32% on the post-change lineup, if responses for the two lineups are independent, the expected probability that observers would respond correctly for just one of the lineups is 45%. This expected value does not differ from our observed rate of 47%, suggesting that observers do not succeed on one lineup at the expense of success on the other.

GENERAL DISCUSSION

The experiments convincingly demonstrate that change blindness for real world attended objects can occur across a range of conditions and is not dependent on the nature of the task or on the manner in which the change occurs. Participants miss changes to people they are interacting with when the experimenters switch by ducking behind a counter (75% change blindness), by occlusion while the participant is photographing them (53% in Expt. 2; 26% in Expt. 3), and when they are giving directions to the experimenters (38% in Expt. 2). These situations vary in terms of the kind of occlusion that masks the switch, the presence of distracting visual-spatial tasks, and the presence of a disruption during the change itself. The experiments also show that successful change detection is associated with relative success in choosing the pre- and post-change experimenters from lineups.

Although these findings are consistent with the hypothesis that change blindness is caused by sparse representations, it is important to note their limits. First, as mentioned above, chance-level lineup performance by participants who miss the change is ambiguous. Unless the lineups are completely sensitive to all of the information participants may have represented about the experimenters, chance-level performance may result from a mismatch between the information necessary to distinguish the target from the distracters and the information participants happened to retain. Second, and more important, the relationship between representations and change blindness is likely to vary across situations (Simons, 2000). For example, participants who miss a change may nonetheless represent many details of the changing objects, and may even represent details that have changed. For example, Simons, Chabris, Schnur and Levin (2002) found that participants who did not detect the disappearance of a basketball in a real-world change spontaneously reported both its presence and its features when asked more probing questions. Also, Angelone, Levin and Simons (2000) tested the relationship between change blindness in attended objects and lineup performance using videotapes. In this case, participants knew they were in an experiment, and they had been told to pay close attention to the video. In some cases, there were no differences in lineup accuracy between participants who did and did not see the change. Findings such as these suggest that change blindness is caused not so much by a failure to represent perceptual detail, but rather by a failure to compare details before and after the change.

The question is, what distinguishes situations where change blindness will be caused by representational failure from those characterized by a comparison failure? A number of factors seem like good candidates. First, if the change is not surprising and does not violate the participants' expectations, it may escape notice, even if the participant has represented the pre-change details. That is, if the meaning of the scene remains unchanged, and the change itself does not draw attention, participants may form representations of the details both before and after the change, but never bother to compare the two. In the absence of a trigger to compare the two representations, observers may fail to detect a change. Furthermore, if the changing details are easily represented in abstract form (for example, if they are easily verbalizable), they might be represented, and easily reported after the change, but not be used in a between-views comparison. Both of these factors might contribute to accurate reports about the disappearing basketball (Simons *et al.*, 2002) as well as the video identity and feature changes (Angelone, Levin, & Simons, 2000). Second, participants' expectations about the experimental situation might lead to different encoding and representation of the elements of the scene (see Simons & Mitroff, 2001). The real-world experiments described above rely on incidental encoding and comparison; before the change, participants do not know they are in an experiment. In contrast, participants in lab experiments (e.g. Angelone, Levin, & Simons, 2000) probably do not limit themselves to only essential visual details. Given that they know they are in an experiment, and are told that they will be answering questions about the stimuli, they probably intentionally code many visual details that would otherwise go unrepresented. However, they do not know that a change will occur. Consequently, even if they encode visual details, they may fail to compare them across views, making the absence of comparison central to change blindness.

Before concluding, we would like to briefly discuss the specific representational failure revealed in these experiments. As reviewed above, our lineup recognition test taps explicit representations, and it does not exhaustively measure all of the information observers might represent from their interaction with the experimenter. These real-world tasks generate a rich perceptual experience, because they require deep processing as part of a social interaction. In our task, participants must process the identity, social category, intentions, and behaviors of the experimenter. They must also process the experimenter's spatial location over time if only to avoid collisions. Thus, we assume a deep and complex perceptual process that is probably activated in all of our participants. The key is that the goal of this processing involves an on-line interaction, and this goal does not necessarily entail creating consciously accessible representations of visual detail.

Of course, people do sometimes form such representations, but they do so primarily in response to specific cognitive demands, which vary across individuals and situations. However, the fact that people have engaged in sophisticated processing raises the possibility that some information was implicitly preserved, even if it was not consciously measured by our recognition task. Although this intriguing possibility could be assessed through more indirect measures (e.g. an analysis of fixations or gaze direction), even if implicit representations did exist, that would not diminish the importance of our claims about explicitly available representations. Change blindness in our task seems to reveal a more specific failure to create a consciously accessible visual representations that can be tracked over time and used later for a recognition test. This failure is important because it goes to the heart of visual experience and leaves us with the impression that we have a rich accessible representation, even though we do not.

SUMMARY AND CONCLUSIONS

The experiments reported here reveal change blindness for real-world attended objects.

Across three different scenarios, a substantial proportion of participants failed to detect a change to their conversation partner. In addition, we found that change blindness is associated with less accurate lineup performance, for both pre- and post-change experimenters. These results suggest that for real-world changes, change blindness is associated with relatively sparse or consciously inaccessible representations of attended objects, although it is important to note that in other situations, change blindness can be caused by other failures as well. These findings suggest that understanding change detection, and more generally scene perception, requires careful consideration of not only how attention selects some objects for further processing, but also how attention selects some features of objects for further processing. Accordingly, attention to an object is not a unitary act that guarantees a complete coding of its features.

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