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The roles of encoding, retrieval, and awareness in change detection

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In the experiment reported here, we examined the processes by which expected (probable) changes are detected more frequently than are unexpected (improbable) changes (the change probability effect; Beck, Angelone, & Levin, 2004). The change probability effect may be caused by a bias toward probable changes during encoding of the prechange aspect, during retrieval of the prechange aspect, or during activation of an explicit response to the change. Participants performed a change detection task for probable and improbable changes while their eye movements were tracked. Change detection performance was superior for probable changes, but long-term memory performance was equivalent for both probable and improbable changes. Therefore, although both probable and improbable prechange aspects were encoded, probable prechange aspects were more likely to be retrieved during change detection. Implicit change detection was also greater for probable changes than for improbable changes, suggesting that the change probability effect is the result of a bias during the retrieval and comparison stage of change detection. The stimuli used in the change detection task may be downloaded from www.psychonomic.org/archive.

What is the process by which people detect visual changes? In the absence of bottom-up information (e.g., abrupt onsets or motion transients) to direct visual-processing resources to the location of a change, changes in the visual environment often go undetected (change blindness: for reviews, see Rensink, 2002, and Simons, 2000). However, visual changes are not always missed, because knowledge about the visual world can improve change detection performance (Beck, Angelone, & Levin, 2004; Hollingworth & Henderson, 2000; Rensink, O'Regan, & Clark, 1997; Shinoda, Hayhoe, & Shrivastava, 2001). Beck et al. found that changes that are likely to occur in the real world (probable changes; e.g., a lamp turning from off to on) are detected more frequently than are changes that are unlikely to occur in the real world (improbable changes; e.g., a blue lamp changing into a green lamp). Therefore, visual information associated with probable changes is selected for processing over visual information associated with improbable changes. The goal of the present article is to determine the locus of this selection of probable changes over improbable changes.

There are several steps of processing necessary for change detection to occur, during which information relevant to probable changes could be more likely to be selected than information relevant to improbable changes (see Figure 1; see Simons, 2000, and Simons & Rensink, 2005, for discussions of the steps necessary for change detection). Here, we will focus on three important steps in change detection; the encoding process, the retrieval and comparison process, and the explicit response process (see Simons, 2000, and Simons & Rensink, 2005, for other discussions of the steps necessary for change detection). In order for a change to be accurately detected, sufficiently accurate, detailed, and stable prechange representations must first be encoded in memory. Attention to the prechange aspect (i.e., the part of the prechange scene that is different form the postchange scene) is necessary for these representations to be formed (Levin & Simons, 1997; Rensink et al., 1997; Simons & Levin, 1998). Second, the prechange memory representation must be retrieved for comparison with the postchange aspect. Finally, the comparison process must lead to the activation of an explicit response to the change. When change blindness occurs, it suggests that the aspect of the visual world that changed was not sufficiently processed at one or more of these steps. Consequently, probable changes are detected more frequently than are improbable changes because the information associated with probable changes is more likely to be sufficiently processed during one or more of these steps in change detection.

The Encoding Process

Successful change detection depends on encoding an accurate and sufficiently detailed representation of the

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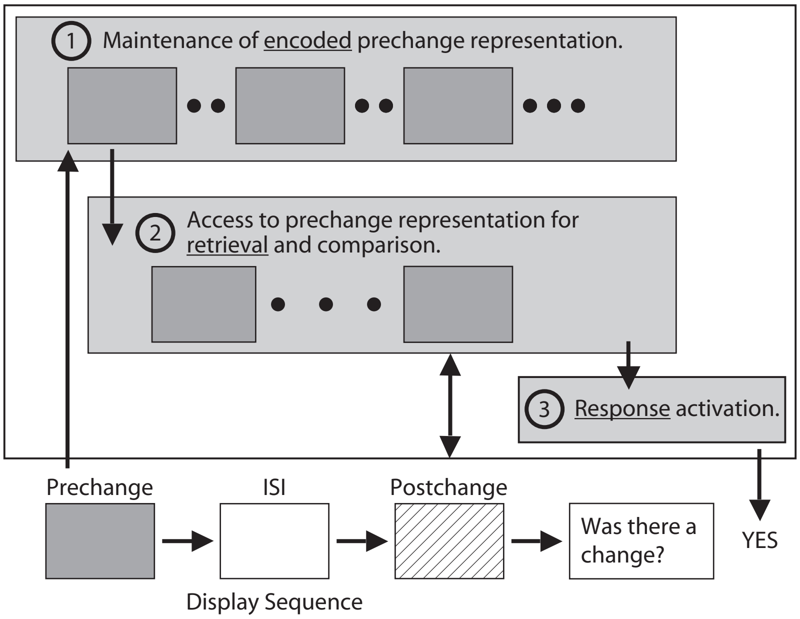

Figure 1. The necessary steps for successful change detection. (1) The prechange aspects must be encoded in memory until the postchange scene aspect is attended, (2) the prechange representation must then be retrieved for comparison, and then (3) an explicit behavioral response to the change must be activated.

prechange aspect. Several studies have arrived at the conclusion that change blindness occurs because memory representations of the visual world are largely gist based and contain little visual detail (Irwin & Andrews, 1996; O'Regan, 1992; O'Regan & Noë, 2001; O'Regan, Rensink, & Clark, 1999; Rensink, 2000; Rensink et al., 1997; Simons, 1996; Simons & Levin, 1997). Encoding a memory representation of the prechange aspect that will support change detection requires attention (Hollingworth & Henderson, 2002; Levin & Simons, 1997; Rensink et al., 1997; Simons & Levin, 1998). However, Levin, Simons, Angelone, and Chabris (2002) found that participants who missed a change in the identity of a pedestrian they were talking to also performed worse on a memory test for the identity of the pedestrian. That is, even though the participants were clearly paying attention to the pedestrian they were having a conversation with, they did not necessarily encode and maintain an accurate and sufficiently detailed memory representation of the pedestrian. Therefore, not everything that is attended is sufficiently encoded into memory; rather, encoding may be biased toward some attended aspects (e.g., the gender of the pedestrian) of the visual world over others (e.g., what the pedestrian is wearing). Most important, when an attended aspect is not encoded, change blindness occurs.

Here, we will examine whether an encoding failure for improbable prechange aspects is the reason why probable changes are detected more frequently than are improbable changes. If so, we would expect that on a long-term memory (LTM) test for probable and improbable prechange aspects, performance should be higher for the probable prechange aspects. Alternatively, if the selection of probable changes over improbable changes does not occur during encoding, memory performance for both types of prechange aspects should be equivalent.

The Retrieval Process

Although change blindness can be caused by a failure to encode a sufficiently detailed and stable memory representation of the prechange aspect, encoding failures may not be the primary cause of change blindness (see Simons & Rensink, 2005, for a discussion). Several researchers have shown that change blindness can occur even when LTM tests reveal accurate memory for the changing aspects (Angelone, Levin, & Simons, 2003; Hollingworth & Henderson, 2002; Varakin & Levin, 2006), suggesting that the cause of change blindness may be the failure to retrieve the encoded representation. In these studies, the participants performed a change detection task, and then their memory for the changing features was tested. Often, LTM performance for the changing aspect was rather high (between 45% and 80%) but change detection performance was much lower (between 12% and 50%). Therefore, change blindness could occur even when a representation of the prechange aspect has been encoded in LTM, suggesting that a failure to retrieve the representation for comparison with the postchange aspect caused the change blindness.

Research demonstrating that changes can be missed even when a prechange representation is encoded in LTM suggests that change detection tasks do not necessarily provide access to representations encoded in LTM. This may occur in the interest of not overloading a limited capacity processing system, such as working memory, which may be involved in the retrieval process. Rather, only a select portion of encoded information may be chosen for retrieval. For example, when a postchange cue (e.g., a brief mask or arrow at the change location) is provided that indicates which object may have changed in a display, change detection performance is greatly improved (Hollingworth, 2003, 2005). Presumably, providing the cue limits retrieval to the prechange representation so that retrieval capacity is no longer overwhelmed. Therefore, even if detailed and stable prechange representations are encoded in LTM, retrieval of the correct representations for comparison may not occur without a cue's indicating which representation should be retrieved.

In addition to stimulus cues (e.g., arrows and masks at the change location), knowledge may be used to bias the retrieval process toward some aspects of the visual world over others (knowledge-based retrieval). For example, knowledge about the probability of changes occurring in the real world may be used to direct processing resources toward visual information that is likely to change (i.e., probable change information). When a stimulus cue is provided in the postchange scene, all cued prechange aspects should be retrieved equally. However, when stimulus cues are not provided, only those aspects of the scenes associated with knowledge-based retrieval cues (e.g., information associated with probable changes) should be retrieved. Furthermore, stimulus cues shown to improve change detection performance are presented after encoding but before retrieval (with presentation of the postchange scene; Hollingworth, 2003, 2005). This means that the cues must be biasing retrieval, rather than encoding. Knowledge-based cues may also be used to direct retrieval to some aspects of the scene over others.

Probable changes may be detected more frequently than improbable changes because representations of probable prechange aspects are more likely to be retrieved and compared with the corresponding postchange aspect. If this is the case, we would expect not only that probable changes would be more likely to be detected explicitly (i.e., participants accurately reporting, "Yes, there was a change"), but also that they should be equally or more likely to be detected implicitly. Implicit change detection occurs when participants fail to explicitly report detection of the change (i.e., participants inaccurately saying, "No, there was not a change") but sensitivity to the change is revealed through some other measure, such as eye movements (Hollingworth, Williams, & Henderson, 2001), reaction times (Fernandez-Duque & Thornton, 2003; Thornton & Fernandez-Duque, 2000; Williams & Simons, 2000), and event-related potentials (Fernandez-Duque, Grossi, Thornton, & Neville, 2003). In the experiment presented here, we measured implicit change detection by monitoring participants' eye movements while they completed the change detection task. Previous research has shown that the duration of eye movements during the processing of real-world visual scenes can indicate the level of implicit change detection (Hollingworth et al., 2001). If participants fail to report the change but look at the postchange region longer than they look at regions of the scene that did not change, we can conclude that they detected the change implicitly.

Implicit and explicit change detection requires encoding and retrieval of a prechange representation for comparison with the postchange aspect. If encoding and retrieval occur for a particular change and the change is not detected explicitly, presumably it has been detected implicitly. Therefore, if both probable and improbable prechange representations are retrieved and compared equally but probable changes are more likely to be explicitly reported (as was found in Beck et al., 2004), implicit change detection should be greater for improbable changes. Alternatively, if probable changes are more likely to be retrieved and compared, implicit change detection should be equivalent for both types of changes (if the degree to which probable changes are retrieved and compared over improbable changes is equivalent to the degree to which explicit change detection for probable changes is greater than explicit change detection for improbable changes) or greater for probable changes.

Explicit Response Activation

If the prechange aspect is encoded and the representation is retrieved for comparison with the postchange aspect, a signal (the change signal) should be sent to processes involved in providing an explicit behavioral response to the change. Signals that are strong enough to pass a threshold for explicit change detection will result in an explicit behavioral response to the change (e.g., "Yes, there was a change"; see Fernandez-Duque & Thornton, 2003; Mitroff, Simons, & Franconeri, 2002). According to signal detection theory, observers set a critical threshold for deciding whether a particular signal is strong enough to result in explicit detection (Green & Swets, 1966). The threshold for explicit detection of change signals that are consistent with expectation (e.g., probable changes) may be lower than that for change signals that are inconsistent with expectation (improbable changes). This would result in an increased likelihood that change signals for probable changes would result in an explicit behavioral response to the change. The possible influence of a response bias (e.g., a lower decision threshold for probable changes) in the change probability effect can be examined in change detection performance by using the signal detection measure A' (Grier, 1971). If the change probability effect is still present when the signal detection measure is used, we can conclude that the change probability effect is not caused by a response bias toward probable changes.

In addition to using signal detection theory to examine the role of a response bias in the change probability effect, we also examined the extent to which the participants would choose a probable description for trials on which they falsely reported that a change had occurred. Occasionally, participants will provide affirmative explicit behavioral responses ("Yes, there was a change") on trials on which there was no change (i.e., a false alarm). If there is a response bias toward reporting probable changes, participants should describe these false alarm change detections as probable changes more frequently than they describe them as improbable changes.

The Present Experiment

One goal of the present experiment was to replicate the change probability effect, in which probable changes are detected more frequently than are improbable changes (Beck et al., 2004). However, the main objective was to examine whether the change probability effect is driven by a bias toward probable changes during the encoding, retrieval, or explicit response step of change detection. In the experiment presented here, participants completed a change detection task with probable change trials, improbable change trials, and no-change trials. In order to examine the role of the encoding step in the change probability effect, following the change detection task, the participants completed an LTM task for the prechange aspects. If an encoding bias toward probable changes is the cause of the change probability effect, we would expect higher memory performance for the probable prechange aspects. The role of the retrieval step was examined by tracking the participants' eye movements during the change detection task as a measure of implicit change detection. If a retrieval bias is responsible for the change probability effect, implicit change detection for probable changes should be greater than or equal to the level of implicit change detection for improbable changes. The role of explicit response activation was tested by using the signal detection measure A' and by examining the participants' descriptions of changes on false alarm trials. During the change detection task, when the participants reported that they had detected a change, they were presented with a four-alternative forced choice (4AFC) and were asked to choose which of the four alternatives best described the change they saw. On false alarm trials, two of the alternatives described probable changes, and two described improbable changes. If the change probability effect is caused by a preference toward reporting probable changes, then on false alarm trials, the change should be described as a probable change more frequently than as an improbable change, and the change probability effect should not be present when the signal detection measure is used.

METHOD

Participants

Thirty-one students (27 of them female and 4 male) from George Mason University participated in this study for course credit. The average age of the participants was 21 years. All the participants had normal or corrected-to-normal vision.

Apparatus

A Power Macintosh G4 (Dual 1 GHz), equipped with a 20-in. (viewable) ViewSonic P225fb capable of running at 120 Hz and running custom software was used to present the stimuli, control the timing of experimental events, and record the participants' response times. This computer was networked to a Dell Pentium 4 machine that collects eye-tracking data in conjunction with an Eyelink 2 system (SR Research). Latency between the machines is 10 msec. The Eyelink 2 tracker has 250-Hz temporal resolution and a gaze position accuracy of less than 0.5° and uses an infrared video-based tracking technology to compute the center and size of the pupils in both eyes. An infrared system also tracked head motion. Even though head motion was measured, the head was stabilized by means of a chinrest. The chinrest was located 61 cm from the monitor.

Materials

Thirty pictures of natural scenes from Beck et al. (2004) were used in this experiment. The pictures were taken with a digital camera and then modified in Photoshop. Ten of the scenes were prechange pictures. The other 20 were postchange pictures, which were identical to the prechange pictures except for one object that changed in some way. For each prechange picture, there was a corresponding postchange picture with an improbable change (e.g., the window was short in the prechange scene, and then it was longer in the postchange scene; see Figure 2) and another corresponding postchange picture with a probable change (e.g., the flag was laying flat in the prechange picture, and then it was blowing in the wind in the postchange picture). There were 10 picture sets, each containing a prechange scene, an improbable postchange scene, and a probable postchange scene.

As has been reported in Beck et al. (2004), the 10 sets of pictures used in the experiment were chosen from an original set of 17. Four raters rated the probability of the probable and improbable changes in the original set of 17. The raters were instructed to rate the likelihood of each change occurring from one glance to the next in their everyday visual environment. They were also told to assume the possibility of people manipulating the environment to cause the change. The ratings were made on a scale from 1 to 7, where 1 indicated a *very likely* change and 7 indicated a *very unlikely* change. The 10 picture sets with the highest differences between the improbable change rating and the probable change rating were used in the experiment. The difference scores for the 10 picture sets used in the experiment were all greater than or equal to 3.75, and all of the ratings were less than 3 for the improbable changes and greater than 5 for the probable changes (for the specific ratings of each change, see Beck et al., 2004).

Beck et al. (2004) carefully controlled for several other aspects that could vary between the scenes, other than the probability of change. They reported that probable and improbable change scenes did not differ on the centrality of the changing object or the size of the change. Furthermore, all the changing objects were rated as highly typical of the scene, with improbable change objects rated as slightly more typical than were probable change objects. Changes in the scenes could be object deletions, additions, replacements, state changes (e.g., turning a lamp from on to off), location changes, or color changes (for more details on the probable and improbable change scenes, see Beck et al., 2004; full-color versions of the pictures used in this study can be found at www.psychonomic.org/Archive).

In addition to the pre- and postchange scenes, 22 no-change scenes that were similar to the change scenes were taken with a digital camera. These scenes did not contain changes. All the pictures were 36.25 × 28 cm, presented at the center of a 30.5 × 40.5 cm screen, and subtended approximately 25º of horizontal visual angle.

Procedure

The participants completed the experiment one at a time, and the entire experiment lasted approximately 30 min. The participants first completed the change detection task and then completed the incidental LTM task. The participants' eye movements were tracked during both tasks.

Change detection task. The participants were instructed that their task was to decide whether or not a change had occurred in each scene. Each participant completed 32 change detection trials. For 22 of the trials, no-change scenes were presented (no-change trials), and for 10 of the trials, change scenes were presented (change trials). The order of presentation of the 10 change trials and the 22 no-change trials was randomized for each participant. Across the 10

Figure 2. Example of a prechange scene and its corresponding probable and improbable postchange scenes. In the probable postchange scene, the flag is blowing in the wind, and in the improbable postchange scene, the bottom right window is longer.

change trials, each prechange scene was presented once; for half of the trials, the probable postchange scene was presented, and for the other half, the improbable postchange scene was presented. Which 5 change trials would contain probable postchange scenes was randomly determined for each participant.

For the change trials, the prechange scene was presented for 6 sec, followed by a 100-msec white screen interstimulus interval (ISI). After the ISI, the postchange scene appeared for 6 sec. For the no-change trials, the no-change scene was presented for 6 sec, and then, after the ISI, the same no-change scene was presented for another 6 sec. For all the trials, a question appeared on the screen asking the participants to press one key if they saw a change in the scene and another key if they did not see a change in the scene. If the participants pressed the key indicating that they saw a change, a 4AFC appeared, and the participants chose which of the four alternatives best described the change they saw (see Figure 3).

The 4AFC for the change trials was the same for both the probable and the improbable changes for each scene. One of the alternatives was the probable change, one was the improbable change, and the final two were changes that never occurred. The two options that were changes that never occurred were the most common written descriptions of changes that the participants in Beck et al. (2004) had given when they incorrectly detected the change. For the no-change scenes, two of the alternatives were possible probable changes, and two of the alternatives were possible improbable changes.

Incidental long-term memory task. Following completion of the change detection task, the participants were asked to complete the incidental LTM memory test. For each of 10 trials, the participants were presented with the prechange scene and either the corresponding probable or the improbable postchange scene. A green arrow pointed to the part of the scene that was different between the two scenes, so the participants would know on which part of the scene to focus their attention for the memory test. The participants' task was to decide which of the two scenes they had seen during the change detection task. The postchange scene presented during the memory task was always the postchange scene not shown during the change detection task. For example, if a participant had seen the probable postchange scene during the change detection task (e.g., the picture with the flag blowing out and the short window in Figure 2), they were presented with the improbable postchange scene (e.g., the picture with the flag laying flat and a long window in Figure 2) and the prechange scene (e.g., the picture with the flag laying flat and a short window in Figure 2) during the LTM test. In this example, the participants had not yet seen the improbable postchange scene and should report that they had seen the prechange scene, not the improbable postchange scene, during the change detection task.

As instructions for the LTM task, the participants were told that they would see pairs of scenes and that one of the scenes in each pair would be a scene that they had seen during the change detection task and the other would be a scene that they had not seen before. They were then instructed that their task was to choose which of each pair was the scene that they had seen during the change detection task. The scenes were presented one at a time for 6 sec each, and the order (prechange scene presented first or postchange scene presented first) was randomly determined, so that on half of the trials, the prechange scene was presented first and on half of the trials, the postchange scene was presented first. Following presentation of

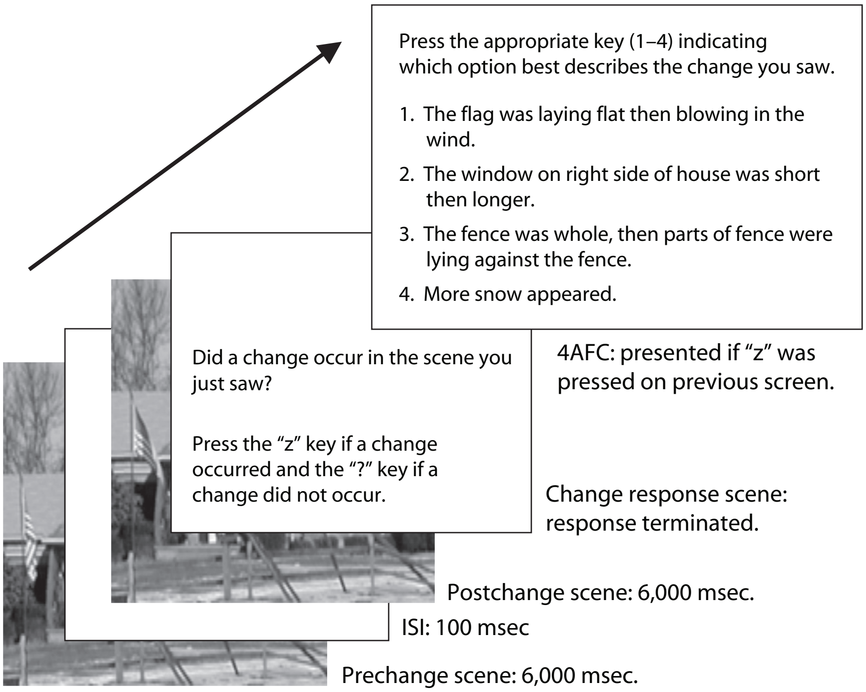

Figure 3. Sequence of events in the change detection task.

the second scene, a question appeared on the screen asking the participants to press one key if they had seen the first scene presented in the first part of the experiment (during the change detection task) and to press another key if they had seen the second scene during the first part of the experiment. The correct answer was always the prechange scene.

RESULTS

Change Probability Effect

Overall, the participants accurately responded *yes, there was a change* to the change trials and *no, there was not a change* to the no-change trials on 70% of the trials. The participants accurately responded that a change had occurred on 60% of the 10 change trials, and they inaccurately responded that a change had occurred (false alarms) on 25% of the 22 no-change trials. The percentage of *yes* responses on probable change trials ($M = 65\%$) was higher than that on improbable change trials ($M = 54\%$) [$F(1,30) = 4.38$, $MS_e = 0.209$, $p = .05$, partial $\eta^2 = 0.127$]. Unless otherwise noted, in the remaining analyses accuracy on the change trials was coded as an accurate change detection only if the participants indicated that a change had occurred and then chose the correct change from the 4AFC. Accuracy on the change trials was 45%, and overall accuracy (change trials and no-change trials) was 65%. Figure 4 displays the mean percentage correct for the probable and improbable change detection trials. The percentage of accurate change detections for probable changes ($M = 52\%$) was higher than that for improbable changes ($M = 38\%$) [$F(1,30) = 6.23$, $MS_e = 0.372$, $p = .02$, partial $\eta^2 = 0.172$; see below for analysis of change probability effect using A']. Therefore, the change probability effect found by Beck et al. (2004) was replicated, with higher change detection performance for probable changes than for improbable changes.

Encoding Bias: LTM

Performance on the LTM test was examined to test whether or not the change probability effect found in the change detection task was caused by a bias toward encod-

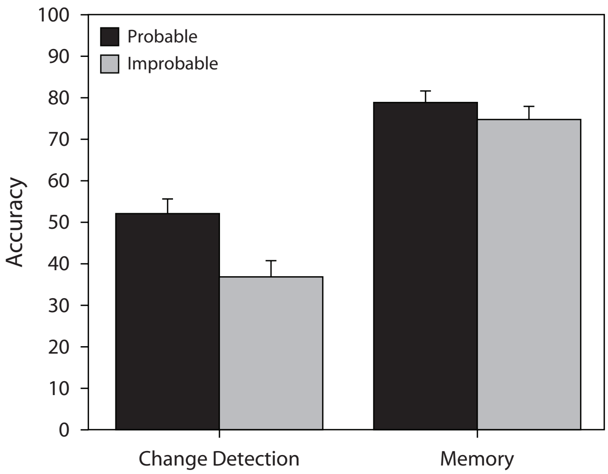

Figure 4. Accuracy (in percentages) for the change detection and memory tasks. Accuracy in the change detection task for the probable and improbable change trials was coded by saying that there was a change and accurately choosing the correct answer to the four-alternative forced choice. Bars represent the standard errors.

ing probable prechange representations over improbable prechange representations. The percentage correct for probable prechange scene (M = 79%) was not significantly different from the percentage correct for improbable prechange scene (M = 75%) [$F(1,30) = 1.0$, $MS_e = 0.032$, $p = .33$, partial $\eta^2 = 0.032$[1]; see Figure 4]. Therefore, the participants were not more likely to have encoded a representation of the prechange aspect of the probable scenes.

Retrieval Bias: Eye Movements

A change region was defined for each probable and improbable change. The change regions were defined as the outline of the portion of the scenes that differed between pre- and postchange scenes, and then this portion of the scene was extended in all directions by 2° of visual angle. Each fixation during the change trials was coded as being either on the change region or off the change region.

If the change probability effect were the result of biased retrieval for probable prechange representations, we would expect higher or equivalent levels of implicit change detection for probable changes. In order to examine the prevalence of implicit change detection for probable and improbable changes, we examined the duration of fixations on the postchange region when the participants failed to report the change. If these fixation durations were longer than those on nonchange regions, we would have evidence suggesting that the changes were detected implicitly. The average durations of the fixations for trials on which the change was not accurately detected were entered into an ANOVA with fixation location (on change or off change) and change type (probable or improbable) as within-subjects factors.[2] The main effect for fixation location was significant; the average fixation duration on the postchange regions (M = 320 msec) was longer than the average duration for fixations off the postchange regions (M = 283 msec) [$F(1,24) = 4.907$, $MS_e = 33{,}874$, $p = .036$]. The main effect for change type was also significant. The participants' fixation durations when they were looking at the probable postchange scenes (M = 318 msec) were longer than those when they were looking at the improbable postchange scenes (M =285 msec) [$F(1,24) = 4.89$, $MS_e = 25{,}730$, p = .037]. Furthermore, the significant interaction between fixation location and change type [$F(1, 24) = 4.47$, $MS_e = 23{,}575$, $p = .045$] indicated that the main effects were driven by a significant difference for the probable change trials between fixation duration on (M = 351 msec) and off (M = 284 msec) the change [$t(25) = 2.7$, $p = .01$] but not for the improbable change trials (on, M = 289 msec; off, M = 282 msec) [$t(25) = 0.33$, $p = .75$; see Figure 5]. Therefore, when the change was not explicitly reported, the participants looked at the probable postchange region longer than they looked at the no-change regions. Furthermore, fixation durations on the probable postchange regions (M = 351 msec) were longer than fixation durations on the improbable postchange regions (M = 289 msec) [$t(25) = 12.9$, $p <$ .01]. Therefore, implicit change detection was found for probable changes, but not for improbable changes, suggesting that the change probability effect is driven by a bias toward retrieval and comparison for the probable prechange representations over the improbable prechange representations.

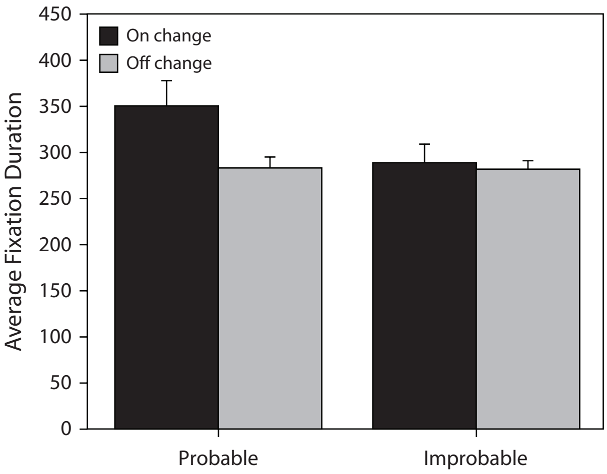

Figure 5. The average durations (in milliseconds) for fixations in the postchange scene as a function of fixation location (on or off the postchange region) for trials on which the change was not accurately detected. Bars represent the standard errors.

It is important for the interpretation of the implicit change detection data to demonstrate that when changes were detected, *both* probable and improbable postchange regions were looked at longer than no-change regions. The average durations of fixations for trials on which the change was accurately detected were entered into an ANOVA with fixation location (on change or off change) and change type (probable or improbable) as within-subjects factors. The main effect for fixation location was significant; the average fixation duration on the postchange region (M = 379 msec) was longer than the average duration for fixations off the postchange region (M = 303 msec) [$F(1,20) = 8$, $MS_e = 121{,}529$, $p = .01$]. However, the main effect for change type was not significant. The participants' fixation durations when they were looking at the probable postchange scenes (M = 307 msec) were not different from those when they were fixating the improbable postchange scenes (M =264 msec) [$F(1,20) = 2.07$, $MS_e = 12{,}100$, $p = .17$]. The interaction between fixation location and change type was not significant [$F(1,20) = 0.62$, $MS_e = 6{,}725$, $p = .44$; see Figure 6]. When a change was accurately detected, fixation durations on the change regions were longer than fixation durations off the change regions, presumably reflecting the added time necessary for retrieval and comparison of the prechange representation.

To further examine whether the longer durations of the fixations on the probable postchange regions on inaccurate change trials (when the change was not accurately detected) is evidence of implicit change detection, we must rule out the possibility that fixations on probable change regions are longer even when a change has not occurred. Therefore, we examined the average durations of the fixations on the prechange regions. For the prechange scenes,

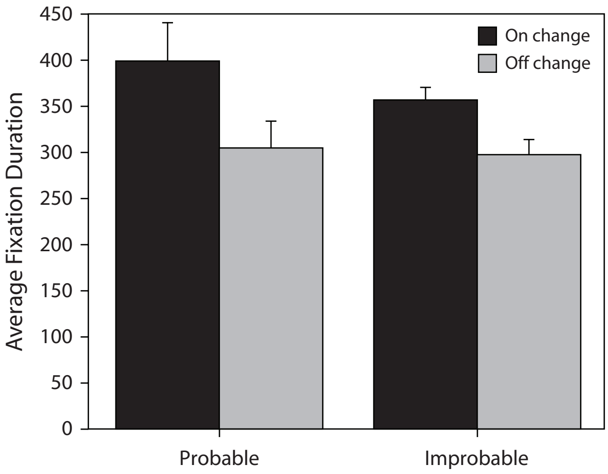

Figure 6. The average durations (in milliseconds) for fixations in the postchange scene as a function of fixation location (on or off the postchange region) for trials on which the change was accurately detected. Bars represent the standard errors.

the duration of the fixations on both the probable and the improbable change regions was calculated for all of the change trials (e.g., for a probable change trial, we examined the duration of the fixations on both the probable prechange region and the improbable prechange region). The average duration of the fixations on the probable prechange regions (M = 302 msec) was not different from the average duration on the improbable change regions (M = 288 msec) [$F(1,30) = 1.2$, $MS_e = 3{,}017$, $p = .29$; see Figure 7]. Therefore, participants do not look at probable change regions longer than they look at improbable change regions prior to a change's occurring, providing further support that the longer durations on the probable postchange regions on the inaccurate change trials is evidence for implicit change detection for the probable changes. Implicit change detection for probable changes, but not for improbable changes, suggests that the change probability effect is the result of a retrieval bias toward probable prechange representations.

It is also important to note that the participants fixated the change region more frequently when they accurately detected a change but that they did not fixate the probable prechange regions more frequently than they did the improbable prechange regions. The proportion of all fixations on the prechange region for each type of trial was entered into a two-factor ANOVA with change detection accuracy (accurate or inaccurate) and change trial (probable or improbable) as within-subjects factors. There was a main effect for accuracy, with a greater proportion of fixations on the prechange region when the change was accurately detected (M = .14) than when the change was not detected (M = .11) [$F(1,22) = 6.78$, $MS_e = 0.023$, $p = .016$; see Figure 8]. However, there was no main effect for change trial. The proportion of fixations on the probable prechange region for probable change trials (M = .12) was not different from the proportion on the improbable prechange region for improbable change trials (M = .12) [$F(1,22) = 0.147$, $MS_e = 0.0004$, $p = .71$]. The interaction between accuracy and change type was not significant [F(1,22) = 0.202, $MS_e = 0.001$, $p = .66$]. Therefore, more frequent fixations on the prechange region improved change detection performance in general, but probable prechange regions were not fixated more frequently than were improbable prechange regions. This further supports the idea that attention is not biased toward probable change regions prior to the change.

Explicit Response Bias: *A′* and False Alarm Change Descriptions

To examine the role of a response bias in the change probability effect, we revisited change detection performance, using the signal detection measure *A′*. The *A′* value for performance on probable change trials ($A' = .60$) was significantly higher than that for performance on the improbable change trials ($A' = .52$) [$t(31) = 4.43$, $p < .01$].[3] Therefore, the change probability effect demonstrated by higher change detection performance for probable changes than for improbable changes was still present even when the data were examined in such a way that response biases were ruled out.

The participants false alarmed to 25% of the no-change trials. Data from 2 participants were not included in the analysis because they did not false alarm to any of the trials. The response chosen for the 4AFC on the false alarm trials was a description of a probable change 53% of the time, which is not different from chance (50%) [$t(28) = 0.474$, $p = .64$]. Therefore, there was no top-down bias toward choosing probable change descriptions, suggesting that the bias toward probable changes does not occur during explicit response activation.

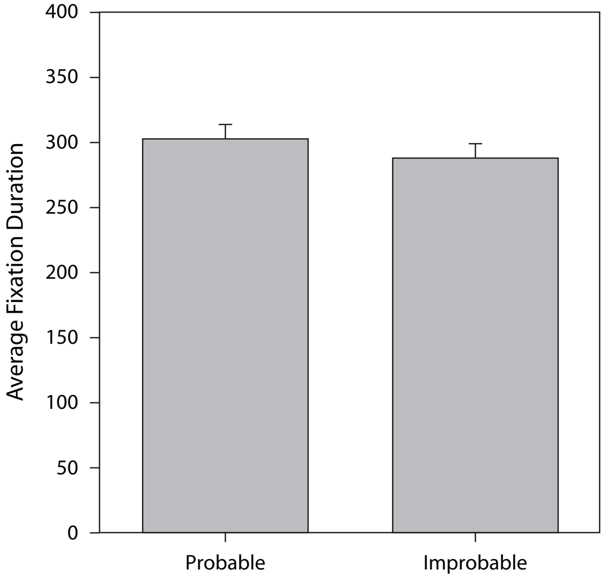

Figure 7. The average fixation durations (in milliseconds) for fixations on the probable and improbable prechange regions. Bars represent the standard errors.

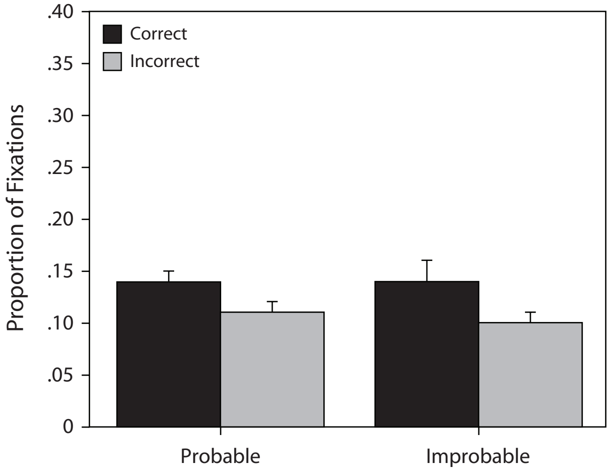

Figure 8. The proportions of all the fixations on the prechange scene that were on the probable and improbable prechange regions as a function of accuracy in the change detection task. Bars represent the standard errors.

DISCUSSION

The change probability effect (Beck et al., 2004) was replicated here, with the participants detecting more probable changes than improbable changes. This demonstrates the importance of knowledge in directing processing resources toward some changes over others. The research presented here suggests that a bias toward probable changes during the retrieval process is the cause of the change probability effect. First, equivalent performance on the LTM test for probable and improbable changes ruled out the possibility that encoding is biased toward probable prechange aspects over improbable prechange aspects. Second, implicit change detection was found for probable changes, but not for improbable changes. Therefore, not only are probable changes detected more explicitly, but also they are detected more implicitly. This suggests that the retrieval and comparison process is biased toward probable changes over improbable changes. Finally, two additional sources of evidence were found against the possibility that a response bias toward probable changes is the cause of the change probability effect. The first source of evidence was that change detection performance for probable changes was still higher than change detection performance for improbable changes when a signal detection measure was used. The second source of evidence was that the participants were no more likely to choose a description of a probable change to describe a false alarm than they were to choose a description of an improbable change. Taken as a whole, these results indicate that the change probability effect is caused by a limited capacity retrieval process that is biased toward probable changes over improbable changes.

The hypothesis that the change probability effect is driven by a bias toward probable changes during retrieval is supported by implicit change detection for probable changes and no implicit change detection for improbable changes. Implicit change detection requires that the prechange memory representation be encoded, retrieved and compared with the postchange aspect but that the result of this comparison not be available for explicit response activation (Ryan & Cohen, 2004). If the bias toward probable changes occurred *after* encoding and retrieval (i.e., during explicit response activation), implicit change detection would be greater for improbable changes than for probable changes. This would be the case because the same number of probable and improbable changes would be encoded and then retrieved and compared but more of these changes would be explicitly reported for the probable changes (as demonstrated by the change probability effect), leaving more of the improbable changes to be detected implicitly. However, we found implicit change detection for probable changes, but not for improbable changes. This demonstrates that even before the stage of explicit response activation, a bias toward probable changes has occurred. This, together with the evidence from the LTM test showing that the bias toward probable changes does not occur during encoding, supports the conclusion that the bias toward probable changes occurs during retrieval.

Causes of Change Blindness

The results presented here also provide additional evidence not only for the cause of the change probability effect, but also for the causes of change detection in general. Specifically, accurate change detection was associated with higher fixation rates on the pre- and postchange regions (for similar findings, see Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2002). Therefore, an attentional bias, during encoding, toward some aspects of the visual world over others leads to better change detection performance for these aspects.

Although an attentional bias during encoding may be the cause of change blindness in some instances, it does not appear to be the cause of the change probability effect. Both probable and improbable prechange aspects were looked at with equivalent frequency and duration. This demonstrates not only that probable prechange regions fail to attract attention preferentially, but also that, when attention arrives, it does not dwell for longer periods of time than it dwells on improbable prechange regions. Therefore, the amount of time spent encoding the prechange region appears to be related to change detection in general, but it is not related to the change probability effect.

Both the change probability effect and change detection in general appear to be related to a failure to retrieve encoded prechange representations. Memory performance was between 75% and 79%, suggesting that the majority of the prechange aspects of the scenes were encoded, but change detection performance was only between 37% and 52%. Therefore, in general, more information is encoded than is retrieved during change detection. This finding is consistent with those of a growing number of reports supporting the once controversial idea that encoding failures account for only a small proportion of change detection failures (Angelone et al., 2003; Hollingworth & Henderson, 2002; Varakin & Levin, 2006). If encoding failures were the main cause of change blindness, the high performance levels on the memory task would predict better performance on the change detection task than was found here. Similarly, if encoding failures were the cause of the change probability effect, we would expect that memory performance for probable changes would be better than memory performance for improbable change. However, the data presented here suggest that encoding failures are not the sole cause of change detection in general and that they are not the cause of the change probability effect.

Conclusion

Research demonstrating participants' inability to detect visual changes has been used to argue for the absence or sparseness of memory representations of the external visual world (O'Regan, 1992; Rensink, 2000; Rensink et al., 1997; Simons & Levin, 1997). This argument has recently been called into question by data showing preserved memory representations in the face of undetected visual changes (Angelone et al., 2003; Hollingworth & Henderson, 2002; Hollingworth et al., 2001; Simons, Chabris, Schnur, & Levin, 2002; for a review, see Simons & Rensink, 2005). This suggests that memory representations of the visual world are frequently encoded but that change detection tasks do not always serve to successfully retrieve these memories. The results presented here speak to the importance of using change detection tasks to discover when LTMs are retrieved and used to aid visual processing. Performance on the LTM test suggests that a fair amount of information in the visual world is encoded into LTM. However, the encoding of visual information may be functionally irrelevant if the memory is not retrieved at the critical moment (e.g., when a change must be detected).

AUTHOR NOTE

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ARCHIVED MATERIALS

The following materials and links may be accessed through the Psychonomic Society's Norms, Stimuli, and Data Archive, www.psychonomic.org/Archive.

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File: Beck-Memory and Cognition-2007.zip

Description: The compressed archive file contains one file:

File1.ext, containing the 10 picture sets (prechange scene with corresponding improbable and probable postchange scenes) used in the present experiment.

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NOTES

1. The effect size of change probability on memory performance is .032 as measured by partial eta-squared in a repeated measures ANOVA. In order for an effect size this small to result in a significant difference ($\alpha = .05$) in memory performance between probable and improbable changes, we would need to run 124 subjects. In order for this effect size to have a power of the ideal level (.8), we would need to run 245 subjects. Therefore, although there may be a slight advantage of memory for probable over improbable changes, this advantage is so small that its contribution to the change probability effect, which has an effect size of .172 and a power of .676, is at best minimal.

2. Six participants were excluded from the analysis because they had missing data in one of the cells; 2 did not have any incorrect probable trials, 1 did not have any incorrect improbable trials, 2 never looked at the probable postchange region, and 1 never looked at the improbable postchange region. For the remaining eye movement analyses, participants were similarly excluded if they had missing data in any of the cells necessary for the analysis.

3. A' is a signal detection measure with a range between . 5 (chance) and 1.0 (perfect sensitivity). In other reports of change detection tasks with a *yes/no* response, A' has been used to examine change detection performance (e.g., Hollingworth, 2004, 2005). The formula used to calculate A' was taken from Grier (1971):

$$A' = \frac{1}{2} + \frac{(h-f)(1+h-f)}{4h(1-f)},$$

where h is the percentage correct for either probable or improbable changes calculated on the basis of the *yes/no* response to the change, ignoring the accuracy on the 4AFC task, and f is the percentage of *yes* responses on the no-change trials (false alarms).

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