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# Visual search for changes in scenes creates long-term, incidental memory traces

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## Abstract

Humans are very good at remembering large numbers of scenes over substantial periods of time. But how good are they at remembering *changes* to scenes? In this study, we tested scene memory and change detection two weeks after initial scene learning. In Experiments 1–3, scenes were learned incidentally during visual search for change. In Experiment 4, observers explicitly memorized scenes. At test, after two weeks observers were asked to discriminate old from new scenes, to recall a change that they had detected in the study phase, or to detect a newly introduced change in the memorization experiment. Next, they performed a change detection task, usually looking for the same change as in the study period. Scene recognition memory was found to be similar in all experiments, regardless of the study task. In Experiment 1, more difficult change detection produced better scene memory. Experiments 2 and 3 supported a "depth-of-processing" account for the effects of initial search and change detection on incidental memory for scenes. Of most interest, change detection was faster during the test phase than during the study phase, even when the observer had no explicit memory of having found that change previously. This result was replicated in two of our three change detection experiments. We conclude that scenes can be encoded incidentally as well as explicitly and that changes in those scenes can leave measurable traces even if they are not explicitly recalled.


**Keywords** Visual search · Long-term memory · Change blindness · Incidental learning

Our everyday environment is highly dynamic. We are surrounded by a multitude of objects, many of which change over time. Some changes, such as the growth of a tree, are too slow to perceive immediately. Other changes, such as the motion of a car or the change of a traffic light, are more rapid and can be noticed as clear dynamic events. Our intuition suggests that the detection of slow changes might be a hard task, demanding good memory. The detection of rapid, transient changes occurring right before our eyes seems intuitively easy and automatic. Indeed, it *is* easy under many circumstances. However, as research on "change blindness" has shown, even instant and very dramatic changes can go unnoticed if some variety of irrelevant transient is used to mask the transients produced by the change (Rensink, O'Regan, & Clark, 1997). Rensink and colleagues were the first to convincingly show that a change can be detected readily if the changing item is attended during the change. Given a small number of items, one could memorize the initial state of each item and detect change by comparing the subsequent state of each item to its prior state. Evidence from the *change detection* paradigm has shown that this can be accomplished for only three or four items, reflecting the small capacity of visual working memory (Luck & Vogel, 1997).

It can also be important to notice changes to scenes that occur over a longer time scale. For example, was that building here the last time I looked? How good is long-term memory for change? What factors affect this memory? One intuitive answer is that good memory for change implies good memory for the prechange state of an object. The more we study an object and its context, the better we should recall or recognize it and its details at a later time (Brockmole & Henderson, 2006). It

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follows that the more thoroughly we study a prechange object, the more likely we are to detect its change when we encounter this object repeatedly, because we will have a more detailed and reliable memory representation to compare with the current visual image. Indeed, it has been shown that change detection performance is affected by previous encoding experience. Brady, Konkle, Oliva, and Alvarez (2009) found that increasing the encoding time of a prechange display improved subsequent change detection, with the most dramatic improvement being observed for the ability to detect slight changes (such as changes in the state of an object). Rosen, Stern, and Somers (2014) showed that previous change detection experience improves the ability to find the same changes in the same scenes repeatedly. They interpreted this finding in terms of memory-based guidance of attention.

The experiments mentioned in the previous paragraph are good illustrations of the *intentional* use of long-term memory (LTM) to guide more efficient deployment of attention when the same environment is encountered again. We are also capable of acquiring and storing significant information incidentally, without any explicit intention to do so. Indeed, numerous studies have shown that people can have good and long-lasting memories for the details of images that have been inspected previously without any instruction to remember (Brockmole & Henderson, 2006; Castelhano & Henderson, 2005; Draschkow, Wolfe, & Võ, 2014; Hollingworth, 2004, 2005, 2006a, b; Hollingworth & Henderson, 2002; Hout & Goldinger, 2010). Other studies suggest that such incidental memories can also be used implicitly—that is, without conscious retrieval—to speed visual search. Maljkovic and Nakayama (1994) showed that the consistency of the target and distractors during a string of visual search trials produces a memory trace that speeds subsequent detection of the same target (*priming of pop-out*). More complex regularities can also be memorized and can facilitate subsequent search in the same context. For example, Chun and Jiang (1998) found that observers show faster detection of a target item when that target is presented in a repeated spatial layout of a search array, even though observers have no explicit recognition of the repeated context. Similarly, many other articles have shown that incidental memory traces can affect the subsequent deployment of attention and eye movements in familiar displays and among familiar items (Hout & Goldinger, 2010, 2012; Howard, Pharaon, Körner, Smith, & Gilchrist, 2011; Körner & Gilchrist, 2007, 2008; Kristjánsson, 2000; Kunar, Flusberg, & Wolfe, 2008; Peterson, Beck, & Vomela, 2007; Peterson, Kramer, Wang, Irwin, & McCarley, 2001).

On the other hand, there are numerous cases in which memory for preceding trials or other exposure to stimuli does *not* improve performance on the current task. For example, observers can show explicit memory for a prechange detail, while nevertheless failing to spot a change in that detail when it occurs (Hollingworth, Williams, & Henderson, 2001; Simons, Chabris, Schnur, & Levin, 2002). In another example of a failure of memory to improve performance, memory of a display does not always speed subsequent searches through that display. For example, Wolfe, Klempen, and Dahlen (2000) had observers search through the same displays of three or six letters several hundred times (with instructions to click on the "E," click on the "R," click on the "E," etc.). The efficiency of these searches did not improve, even though observers had essentially perfect memory of the arrays. In this case, accessing memory for the location of the target appears to take more time than simply repeating a visual search as if the display had never been seen before (Kunar et al., 2008; Oliva, Wolfe, & Arsenio, 2004).

As tasks become more complex, the benefits of repeated search are more likely to be seen. Thus, in search for objects in photographic scenes, search did not improve over multiple searches for different objects in the same scene. However, when an object became the search target a second time, reaction times dropped quite dramatically (Wolfe, Alvarez, Rosenholtz, Kuzmova, & Sherman, 2011). Võ and Wolfe (2012, 2013) used eyetracking to study how memories for targets and contexts guide the deployment of attention during repeated visual search for items in realistic scenes. They found an improvement in performance only when observers repeated a search for a specific target (Võ & Wolfe, 2012). The benefit was not seen if observers had previously searched for other targets at the same locations (letters superimposed on targets). Nor was there a benefit of free viewing or explicit memorization. In an attempt to explain why previous incidental experiences with a scene and with objects in that scene had little effect on repeated search, Võ and Wolfe (2013) suggested that guidance based on general semantic knowledge might trump the use of more specific memories. That is, our understanding of the location of *typical* object in *typical* scenes might be more powerful than information about specific objects seen in specific scenes. For example, if you know that a clock is generally located on the wall, then you guide your attention to the wall without needing to recall that the clock was or was not there when you tried to memorize the scene. Only a very specific memory, created by the act of previously searching for and finding the clock in the same scene, seems to produce an effect above and beyond this general scene guidance effect.

Thus, to summarize, we know that scenes are easy to encode into memory and to recognize days or weeks later. We know that repeated search through the same scene is speeded when the target of search on the current trial is something that has been the target of search on a preceding trial. We also know that search for a change in a scene can be a laborious process. Would the act of finding a change produce the sort of memory trace that could speed a subsequent task? Would performing a change detection task during the study phase increase the chances of recalling a scene during a subsequent test phase? Finally, would performing that change detection task speed subsequent detection of the same change, even if an observer did not explicitly remember that change? In the studies presented here, we used a paradigm combining the critical aspects of change blindness laboratory research (Rensink et al., 1997) and repeated visual search of scenes (Võ & Wolfe, 2012, 2013). This approach is somewhat similar to that implemented by Rosen et al. (2014) in their change detection experiments. However, we used a substantially elaborated method in order to investigate more general issues. We used two different tasks during the first, familiarization/study stage of the experiments: a change detection task that could produce implicit scene memorization, and an explicit memorization task. At test, we could examine the effects of explicit versus incidental learning. We investigated whether scene memory formed incidentally during the course of a change detection task differed from that formed explicitly during the intentional memorization of scenes and objects. We also asked about the effects of explicit versus incidental learning on change detection during the test phase. Finally, and critically, in most prior studies of repeated search or change detection, repeated displays had been presented shortly after the initial ones. Here we used a long (two-week) delay between the familiarization and test phases. In the experiments presented in this article, we sought to determine whether the effort to detect a change in a scene in a familiarization phase produces a robust, if incidental, memory for the changed scene and/or for the change itself. We did not find evidence for enhanced scene memory, but we did find evidence for enhanced implicit memory of the change.

## Experiment 1

### Method

#### Participants

In total, 24 students at the Moscow Higher School of Economics (18 female, six male; mean age 19 years old) took part in the experiment for extra course credits. All reported having normal or corrected-to-normal visual acuity and no neurological problems. All participants signed informed consent before the beginning of the experiment.

#### Stimuli

A total of 97 photographic images were used in the experiment, each having two versions—the original one and its modification, which differed in one object from the original. This set of stimuli was selected from three databases tested in previously published studies, providing a wide variety of scene categories. The scenes from Rensink et al. (1997; 38 images) were predominantly pictures of outdoor locales and of people. Those from Utochkin (2011a, b, 33 images) were outdoor scenes and animals, whereas Sareen, Ehinger, and Wolfe (2016; 26 images) provided indoor scenes. One scene from Rensink et al. was always used for a demonstration trial at the beginning of the experiment. Of the remaining 96 images, 64 were selected for presentation during the study phase. These were sampled from the three databases in roughly the same proportions as in the entire set (i.e., 25 or 26 images from Rensink et al., 1997; 22 images from Utochkin, 2011a, b; and 16 or 17 images from Sareen et al., 2016). These specific sets of 64 images varied across participants, so that each image was seen approximately equally often in the study phase. The remaining 32 images were used as new images in the test phase only. Stimuli were presented and responses were recorded via PsychoPy (Peirce, 2007).

To create the changed image, one object in each original image was altered in whole or in part. For instance, an animal in a crowd of other animals, a helicopter in the sky, or a picture on a wall might be removed, spatially shifted, or changed in color. Alternatively, the change could affect part of an object such as part of an island, the shirt on a person, or the tower of a church. The total area subtended by a changing detail on a screen was approximated by an area of an ellipse circumscribing the change, if the changed region had no substantial convexities. Less regular regions were approximated by a sum of several ellipses. These physical areas were then scaled by Teghtsoonian's (1965) power function with an exponent of 0.76 in order to obtain psychophysically grounded perceived areas. The perceived areas varied widely, from ~1.1 to ~118.6 squared degrees. Because the changed objects were seen from a wide variety of distances in the original images (from inches to miles), the angular sizes were not strongly correlated with the real sizes of the changed areas.

#### Procedure

**Study phase** During the study phase, observers performed a standard change blindness task. On each trial, an image was presented in alternation with the modified version of that image. A blank, gray screen was inserted between repeated presentations of the original and altered images (Fig. 1). Each image was presented for 300 ms, and the blank screen was presented for 100 ms. Therefore, one full cycle of image alternation (original image, altered image, and two intervening blank screens) took 800 ms. Participants were asked to find an object that changed between the two views and to press the space bar on a keyboard when they had found the change. The button press stopped the image alternation, and the original version of the image was presented with an instruction asking the participant to click on the location of the changed object with a mouse. Note that the observers were encouraged to click on the middle of the target object; this was done to

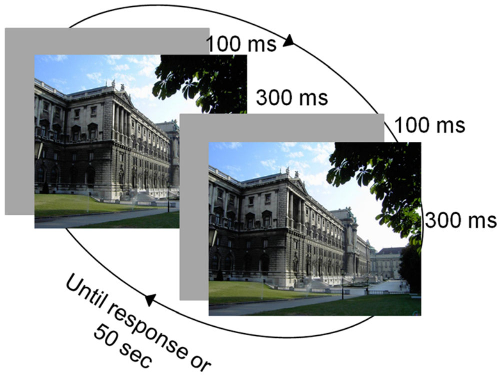


**Fig. 1** Time course of a trial in the change blindness task.

diminish ambiguity in subsequently classifying the click coordinates as belonging to targets or to adjacent nontargets. If a participant had failed to find the change in a string of alternating images within 50 s, the alternation stopped. In total, each participant received 64 images during the study phase.

**Test phase** The second phase of the experiment took place exactly two weeks after the study phase. Here, 32 new images were mixed with the 64 old ones. Each trial started with the presentation of an image and two instructions: (1) determine whether this is an old or a new image, and (2) click on the location of the change, if they could remember it. For the second task, they were asked to press the space bar if they believed an image was new or could not recall the change location in an old image. The original versions of each image were used for the memory test. That is, the target detail that would be changed was always present and shown in its original location and color.

After reporting on their memory for the scene and the location of the change, observers performed the change detection task as they had done two weeks prior. Each change in an old image was the same change that had appeared in the study phase. If the image was new, obviously the change was novel as well.

### Data analysis

**Memory performance** Since our participants performed two memory tasks on each image (old/new discrimination and cued recall of the change location), we had two types of memory data—scene recognition memory and cued-recall memory for the changed object. For *scene recognition memory* we calculated a nonparametric sensitivity index $A'$, based on the hit (proportion of correct recognition of old images) and false alarm (proportion of false recognition of new images) rates (Stanislaw & Todorov, 1999). The nonparametric index was used because it did not require the implementation of critical statistical assumptions from signal detection theory that have not been tested for our data. Changed-object cued-recall responses were labeled as correct if the target was localized correctly, and incorrect if the participant did not click on a target at all or mislocalized and misidentified it. The target was considered to be correctly localized if the click coordinates were inside the ellipses circumscribing that target. For the 64 old scenes, the scene recognition and object cued-recall measures were combined to categorize memory as taking one of *three states*: (1) no scene memory, in which the old scene had not been recognized; (2) no object memory, or correct scene recognition but incorrect or lack of object recall; and (3) full memory, or correct scene recognition and correct object recall. This classification was applied to each memory report for the old scenes.

**Change blindness data** The principal measure for estimating performance in the change blindness task was the search time—the time required to find the change in the alternating images. The search time data were analyzed only for trials with correctly localized changes; trials with mislocalized changes or undetected changes were excluded from the analysis.

## Results and discussion

Of the 24 original participants, five did not return for the test phase two weeks later, so the data from 19 participants were analyzed. In all, 2.3% of trials were excluded from the analysis because participants failed to detect a change in the study phase; those trials were not taken into account during the test phase. In the test phase, an additional 1.2% of trials were excluded from the change detection RT measure because the change was never detected. However, those trials were included in the analysis of recognition and recall.

### Memory for scenes and changes

In the test of recognition memory for scenes, participants showed on average 67.2% ($SD$ = 17.9%) hits and 15.2% ($SD$ = 8.7%) false alarms; $A'$ was therefore .85 ($SD$ = .07; note that the maximum $A'$ value is 1.0). This shows strong recognition memory for scenes over a delay of two weeks (Nickerson, 1968; Shepard, 1967), though such memory is naturally weaker than in immediate recognition (Brockmole & Henderson, 2006; Konkle, Brady, Alvarez, & Oliva, 2010). For change recall memory, we observed the following distribution of reports among the old scenes: 32.8% ($SD$ = 17.9%) for no scene memory, 40.9% ($SD$ = 12.3%) for scene memory with no object memory, and 26.3% ($SD$ = 12.4) for full memory. This result shows that observers were markedly less likely to remember the changes to scenes than to recognize the scenes themselves. Moreover, the percentage of recalled changing objects was much lower than has been reported previously in the literature on the incidental (Castelhano &

Henderson, 2005; Hollingworth, 2004, 2006a, b) and intentional (Andermane & Bowers, 2015; Brady, Konkle, Alvarez, & Oliva, 2008; Castelhano & Henderson, 2005; Gehring, Toglia, & Kimble, 1976; Standing, 1973) memorization of objects. Note, however, that those previous studies had used recognition rather than cued-recall memory tests and shorter retention intervals. Thus, the dramatic differences in the estimates of object memory are likely to be explained by the substantial differences between those procedures and ours in Experiment 1.

Note that, in this section, we are only reporting descriptive statistics on memory performance and comparing them to references in the literature. We were analyzing the effect of no specific independent variable on memory within this experiment. We will return to scene recognition data below, in the General Analysis of Memory Performance in Experiments 1–4, where memory performance will be compared across all experiments.

### Search for changes

The average times to detect changes are shown in Fig. 2a. As can be seen in the figure, if they had no memory for the scene, observers took as long to find the change in the test phase as they had in the study phase. Given full memory, unsurprisingly, observers were very fast to localize the change during the test phase. A repeated search in the full-memory condition took only about one or two cycles of the two images, much faster than the times at the two other memory levels ($p < .001$, Bonferroni-corrected). Of most interest, when observers remembered the scene but reported no overt memory for the change, they nonetheless were faster to find the change at test than in the study phase. To assess these results statistically, a 2 × 3 within-subjects analysis of variance (ANOVA; Phase [study or test] × Memory Level) was run, including the observer's identity as a random factor. Only correct trials were included. The difference in search times between the study and test phases was highly significant [$F(1, 21) = 108.63$, $p < .001$, $\eta_p^2 = .836$]. The effect of memory level was also highly significant [$F(2, 49) = 41.48$, $p < .001$, $\eta_p^2 = .627$]. The interaction between phase and memory level was also significant [$F(2, 58) = 36.62$, $p < .001$, $\eta_p^2 = .558$].

As we noted, the most interesting question is whether change detection was faster in the test phase than in the study phase on those trials on which there was no explicit memory for the change at test. Thus, the comparison of most interest was between trials with no object memory at test and the original study phase change detection for those stimuli. Change detection was significantly faster in the test phase ($p < .001$, Bonferroni-corrected), suggesting that implicit memory speeded change detection even in the absence of explicit recall of the change location. In the no-scene-memory trials, the searches in the study and test phases did not differ significantly in duration ($p > .999$, Bonferroni-corrected). Thus,

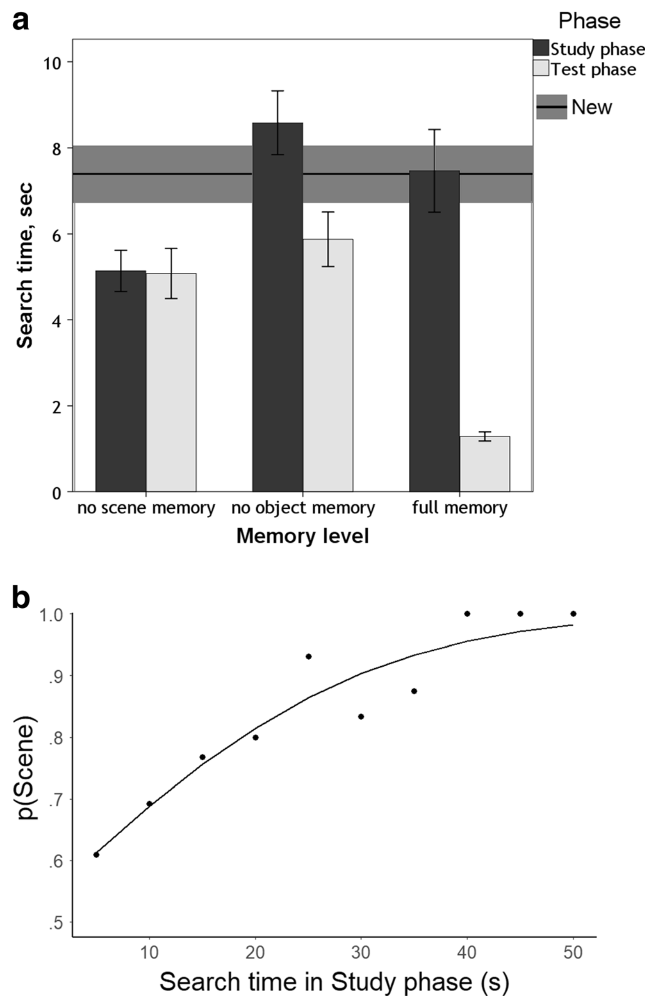


**Fig. 2** **a** Average search times as a function of memory level in Experiment 1. Error bars and the gray zone around the baseline denote 95% CIs in the corresponding conditions. **b** Model fit plotting the probability of scene recognition *p*(Scene) as a function of search time in Experiment 1.

when observers did not remember seeing the original scene, change detection times did not differ between study and test. Note, however, that both the study and test change RTs were relatively fast in the no-scene-memory condition—faster than the change RTs for totally new images (gray horizontal bar in Fig. 2a). We will return to this point. Post-hoc tests showed that these no-scene-memory trials produced faster search for change than did the two other conditions in the study phase ($p < .001$, Bonferroni-corrected; Fig. 2a). For no-object-memory and full-memory trials, however, repeated searches for change were faster than the initial searches ($p < .001$, Bonferroni-corrected).

The search times in the test phase were compared to those for new images presented for the first time in the test stage. Comparisons were done for all three types of trials (the three gray bars in Fig. 2a), all of which showed faster search than for the new images (no scene memory, $p < .001$; no object memory, $p = .001$; full memory, $p < .001$; all Bonferroni-corrected).

Figure 2b shows the probability of recalling a scene [*p*(Scene)] in the test phase as a function of the time it took to find the change in that scene during the study phase. The *p*(Scene) was the total of the proportions of no-object-memory and full-memory trials. Scenes were grouped into ten 5-s bins, and the probability of recall was calculated within those bins. As Fig. 2b shows, there was a strong relationship between search time and subsequent recall of the scene (Probit regression, $R^2$ = .903); little relationship between search time and subsequent recall of the *change* (i.e., the proportion of full-memory trials) in that scene ($R^2$ = .059); and little or no relationship of the physical size of the change to any of the measures of interest (search time, linear regression: $R^2$ = .045; probability of recalling the scene: $R^2$ = .001; probability of recalling the change: $R^2$ = .049). These findings are in line with the previously reported absence of correlations between the angular size of an object in change detection (Rensink et al., 1997) and memory for both scenes (Isola, Xiao, Parikh, Torralba, & Oliva, 2014) and individual objects (Milliken & Jolicœur, 1992).

The relationship between search time in the study phase and the probability of recalling the scene in the test phase may be related to a curious aspect of the data, mentioned above: Observers were fast to find changes during the test phase in the no-scene-memory conditions (the first gray bar in Fig. 2a). They were faster in this condition than to find changes in totally new scenes. One possibility is that they had some implicit memory of the change, even though they had no explicit memory of either the scene or the change. However, an alternative possibility is shown in the fast change detection for those same images when they first appeared in the study phase: These may simply have been easy change detection scenes, so the change was also found quickly in the study phase. As a result, observers spent little time with the scene. It thus was poorly encoded into memory, but the change remained easy to find de novo when it was presented a second time during the test phase. To test this hypothesis, we forced longer engagement with each scene in Experiment 2.

# Experiment 2

## Method

### Participants

A total of 24 students at the Higher School of Economics (21 females, three males; mean age 19 years old) took part in the experiment for extra course credit. All reported having normal or corrected-to-normal visual acuity and no neurological problems. All participants signed informed consent before the beginning of the experiment.

### Stimuli

The stimuli were exactly the same as those used in Experiment 1.

### Procedure

The procedure was the same as in Experiment 1, with one important modification in the study phase: A lower limit of 10 s was imposed on the exposure to each image. If the change were detected in less than 10 s, observers were instructed to repeatedly tap the space bar until the 10-s period had finished. Observers were told a story about a programming "bug" that made this irrelevant activity necessary. The measures and data analysis were the same as in Experiment 1.

## Results and discussion

Of the 24 participants, four did not arrive at test phase, so the data from only 20 participants were analyzed. A total of 4.6% of the trials were excluded from the analysis because participants failed to detect a change during the study phase; those trials were not taken into account in the test phase. Also, 1.4% of trials were excluded from the analysis of search times because the changes were not detected; however, those trials were included in the analysis of recognition and recall.

### Memory for scenes and changes

In the test of recognition memory for scenes, participants showed on average of 63.9% (*SD* = 14.3%) hits and 12.8% (*SD* = 11.3%) false alarms, which corresponded to $A'$ = .84 (*SD* = .08). For change recall memory, we found the following distribution of reports among old scenes: 36.1% (*SD* = 14.3%) for no scene memory, 46.7% (*SD* = 13.1%) for no object memory, and 17.2% (*SD* = 12.5) for full memory.

### Search for changes

Figure 3a shows the times required to find changes in the scenes in the study and test phases for the three categories of test phase memory. The pattern is similar to that in Fig. 2a. When observers had no scene memory, changes were found in the same amount of time in the study and test phases. In the full-memory condition, changes were found more quickly in the test phase. Most importantly, changes were also found more quickly in the test phase in the no-object-memory condition. As in Experiment 1, some implicit knowledge seems to have helped observers find the change more rapidly, even when there was no overt recall of that change.

As in Experiment 1, this basic pattern of results was supported by a 2 × 3 within-subjects analysis. For no-object-memory and full-memory trials, change detection was faster in the test phase than in the study phase ($p < .001$, Bonferroni-

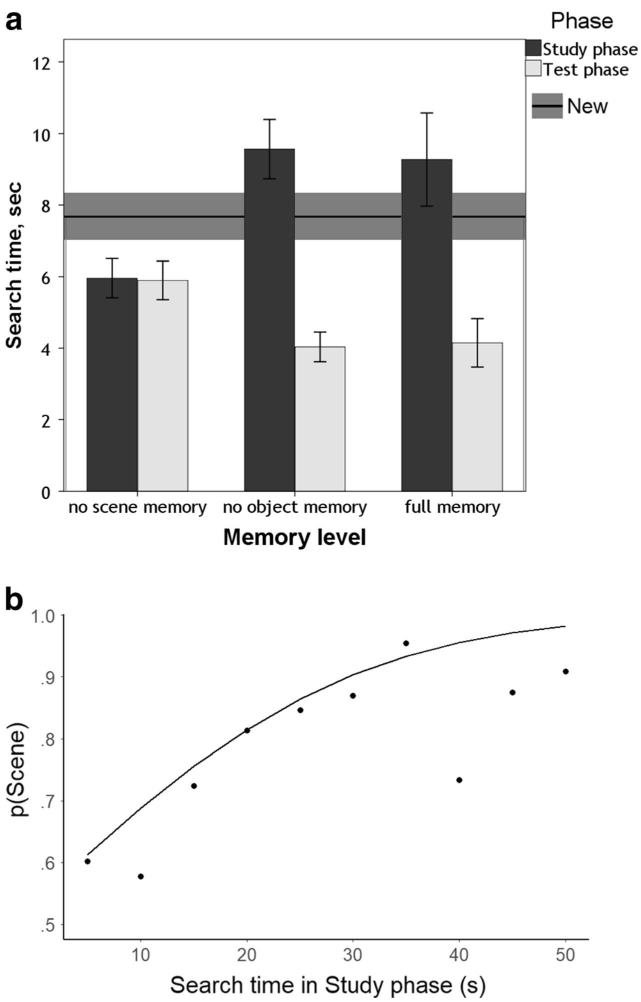


**Fig. 3** **a** Average search times as a function of memory level in Experiment 2. Error bars and the gray zone around the baseline denote 95% CIs in the corresponding conditions. **b** Model fit plotting the probability of scene recognition *p*(Scene) as a function of search time in Experiment 2.

corrected). Again, change detection was faster in the test phase even when observers did not explicitly remember the change. The enforced 10-s minimum did not qualitatively change the no-scene-memory condition, in which change detection was fast in the study phase and unchanged in the test phase.

Specifically, an effect of the phase on the search times was highly significant [$F(1, 34) = 91.08$, $p < .001$, $\eta_p^2 = .727$], showing that the average search was faster at test than in the study phase. The effect of memory level was also significant [$F(2, 49) = 4.17$, $p = .021$, $\eta_p^2 = .147$]. The Phase × Memory Level effect on the search times was significant as well [$F(2, 77) = 63.29$, $p < .001$, $\eta_p^2 = .623$]. A series of post-hoc tests showed no differences between memory levels during the study phase, except for the no-scene-memory condition, which yielded faster search than in the other two conditions ($p < .001$, Bonferroni-corrected). At the same time, there was no difference between initial and repeated searches in the no-scene-memory condition.

The search time was significantly slower for new images in the test phase than for no-scene-memory trials in the study phase, but it was faster than search on no-object-memory trials in the study phase ($p < .001$, Bonferroni-corrected) and did not differ from search on full-memory trials in the study phase ($p = .161$, Bonferroni-corrected; Fig. 3a). Repeated search for change at each of the three memory levels was faster than search in the new trials ($p < .001$, Bonferroni-corrected; Fig. 3a).

Figure 3b shows the relationship of initial search time to memory for scenes. As in Experiment 1, a regression analysis showed that search time explained a large percentage of variance in the memory for scenes ($R^2 = .650$, Fig. 3b). Thus, if you find the change quickly, you are less likely to remember the scene. Speed of finding the change in the study phase explained a substantially lower percentage of the variance in test phase memory for targets ($R^2 = .247$).

Thus, the results of Experiment 2 largely replicated those of Experiment 1, with some minor differences (such as faster change detection RTs for new images in the test phase than for some initial searches in the study phase). Most importantly, we replicated poor scene memory for scenes with fast change detection RTs in the study phase. Since observers looked at those images for 10 s, this finding cannot be explained as a mere exposure effect. Perhaps instead this is a "depth-of-processing" effect (e.g., Craik & Lockhart, 1972), with harder, longer initial searches for change yielding stronger memory two weeks later.

As in Experiment 1, regression analyses showed that the size of the changing target explained a very small percentages of the variance in search times in the study phase ($R^2 = .015$) or in either *p*(Scene) ($R^2 = .005$) or *p*(Object) ($R^2 = .090$). We concluded that the angular size of the change did not substantially affect either scene memory or change detection performance in Experiment 2.

## Experiment 3

In Experiment 3 we examine the hypothesis that depth of processing in the test phase is a factor in the recall of scenes and/or the speed of detecting change in the study phase. The depth-of-processing hypothesis can be subdivided into several questions when considering memory for scenes and for changes in those scenes. Is the whole scene encoded more deeply as search progresses? Alternatively, are some individual objects encoded more deeply, allowing them to serve as cues to retrieve the scenes and guide repeated search for the change? Although it is difficult to probe the depth of processing of any individual object during search in natural scenes, one particular object—namely the changing target—can be used as a potential candidate for doing so. As has been demonstrated before (Draschkow et al., 2014; Võ & Wolfe, 2012), the search target has a great memory advantage over all other items (distractors), probably indicating its deeper processing (Craik & Lockhart, 1972). In the change blindness task, the changed object is just another distractor object until the change is found. Thus, we can assume that the depth of processing of the changed object is relatively high if the change is found, and relatively low if it is not. We used this property of the target in Experiment 3 to test whether LTM for the scene and the speed of a second search for a change are affected by whether or not the observer found the change during the study phase. Does successfully finding the change in a scene contribute to the memorability of the entire scene and/or the speed of finding a subsequent change?

## Method

### Participants

In total, 22 students at the Higher School of Economics (17 female, five male; mean age 18 years old) took part in the experiment for extra course credit. All reported having normal or corrected-to-normal visual acuity and no neurological problems. All participants signed informed consent before the beginning of the experiment.

### Stimuli

In Experiment 3, the same set of images was used as in Experiments 1 and 2. In addition, seven new images were taken from the databases mentioned in the Stimuli section of Experiment 1. For these new images, their modified versions had two changes rather than one.

### Procedure

**Study phase** During the study phase, participants performed the change blindness task. Again, 64 images were chosen out of 96 initial images for presentation to each participant. However, only half of them contained a change during the alternation display, and the other half contained no change. Also, seven new, double-change images were added to the 64 images, so that the total number of trials was 74. The images were presented in a random order.

Participants viewed each alternating image for a fixed time of 20 s (double the mean search time from Exp. 1). Observers were told that each image could contain one, two, or no changes. The participants were instructed to find as many changes as they could during the flicker interval. After 20 s, participants reported the number of changes and clicked on the locations of those changes.

By using the double-change trials and the fixed exposure time, we forced our participants to be involved in search activity for the same amount of time with the one-change and no-change images. The potential for a second change induced our participants to continue searching even after detection of a first change. Thus, any differences between the one-change and no-change conditions could be ascribed to the effects of detecting a change during the study phase.

**Test phase** In general, the test phase was similar to those in Experiments 1 and 2. The important change concerned the no-change scenes from the study phase. In the test phase, these now contained a change, so we could measure the time to find a change in those scenes. The seven additional, two-change trials from the study phase were not used in the test phase because there would be too few to provide reliable statistics, and these scenes had no specific purpose other than to encourage search in the study phase.

## Results and discussion

Of the 22 participants, four did not arrive at the test phase, so the data from 18 participants were analyzed. A total of 8.3% of trials were excluded from the analysis of search times in the test phase because participants failed to detect a change. However, those trials were included in the analysis of recognition and recall.

The measures were exactly the same as in Experiment 1. However, change detection times were analyzed only for the test phase, because the study phase did not involve an immediate response upon detection. Figure 4 shows the times required to find the change in the scene during the test phase. The conditions were somewhat different from those of the previous two experiments. From left to right in the figure, the bars represent (1) entirely new scenes; (2) scenes that had no change during study and were not remembered at test; (3) scenes that had no change during study and *were* remembered at test; (4) scenes that had one change during study but were not remembered at test; (5) scenes that had one change during study and *were* remembered, but where the change was not remembered; and finally, (6) scenes that had one change during study and both the scene and the change were remembered at test. Recall that the scenes with two changes were not included in the test phase.

### Memory for scenes and changes

In the test of recognition memory for scenes, participants had on average 66.7% ($SD$ = 14.3%) hits and 7.6% ($SD$ = 13.9%) false alarms, which corresponded to $A'$ = .87 ($SD$ = .15). For change recall memory, we found the following distributions of reports among old scenes: 33.2% ($SD$ = 14.3%) for no scene memory, 52.1% ($SD$ = 12.3%) for no object memory, and 14.7% ($SD$ = 6.4) for full memory. Specifically, within scenes in which a change was presented in the study phase and observers noticed it, the three memory levels were distributed as 23.5%, 43.32%, and 33.19%, respectively. Within scenes in which a change was absent or went unnoticed, there were only

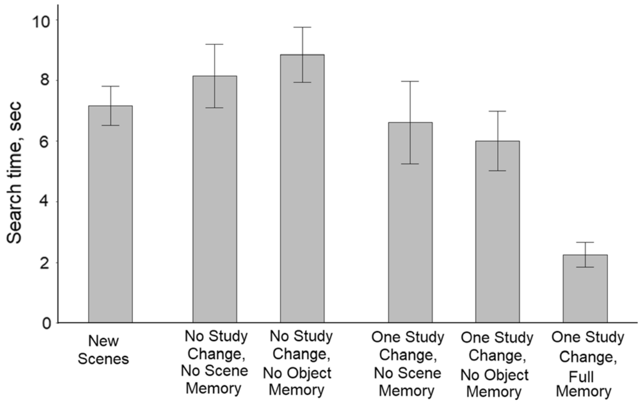


**Fig. 4** Average search times as a function of memory level and number of study changes in Experiment 3. Error bars denote 95% CIs in the corresponding conditions.

two possible memory levels: no scene memory (40.0%) and no object memory (58.7%) (1.3% reports were classified as full memory, but these targets were recalled by coincidence, since they had never been reported during the study phase).

To estimate whether prior change detection affected scene memorability, a *t* test was applied to the analysis of hit rates for old images that had no changes or one change in the study phase. The effect of number of changes was significant [$t(17) = 2.43$, $p = .027$]. This shows that the percentage of recognition for the scenes having one change ($M = 72.22$, $SD = 13.34$) was actually higher than that for the scenes without changes ($M = 61.11$, $SD = 20.54$).

Our central goal in Experiment 3 was to investigate whether finding a change during initial search affected scene memorability. Finding a change did have an impact on memory for scenes: Memory was a bit worse for scenes without a change. The finding that detection of a change improves subsequent LTM for scenes is particularly interesting. In the memory literature, the reverse phenomenon, referred to as the Zeigarnik effect, has been described (Zeigarnik, 1938). In accordance with Zeigarnik's demonstration, incomplete tasks are remembered better than complete ones. In terms of our paradigm, this would predict that observers should remember scenes in which they fail to find any change better than scenes in which they find one change. However, our task implied that observers should continue to search even if one target was found. That is, the task remained incomplete both when one target was found and when none was found, so it is not likely that our procedure provided any strong grounds for the Zeigarnik effect. Our explanation for better recognition of scenes with one found change is based on depth of processing (Craik & Lockhart, 1972). When observers search for a change, they encode some of the scene's features. Finding a target provides deep encoding of at least one object in the scene (Draschkow et al., 2014), which can then be used as an additional retrieval cue for the entire scene.

### Search for changes

The average change detection times are shown in Fig. 4. Of course, when observers explicitly remembered a change, their change detection RTs were fast. Interestingly, there were no significant differences between the other categories of trials (all $ps > .6$, Bonferroni-corrected). The methods of Experiment 3 eliminated the difference between no-scene-memory and no-object-memory trials. However, they also eliminated the evidence that finding a change in the study phase makes it easier to find that change in the test phase, even when the change is not explicitly remembered. In this experiment, we observed no effect of the presence of a change in the study phase.

The results from the scenes with two changes in the study phase suggest that observers did continue to search after finding the first target. In double-change trials, observers found at least one change on average 88.9% of the time ($SD = 13.5\%$). If they detected one change, they also detected the second change on average on 70.1% of trials ($SD = 27.5\%$). The detection rate for the second targets was lower than that for the first targets. This is consistent with the "satisfaction of search" phenomenon, first named in radiology, in which the detection of one target reduces the chance of detecting a second (Fleck, Samei, & Mitroff, 2010). In this case, the explanation of the drop may be fairly simple: If observers have an 89% chance of finding one change, they will have an 89% × 89% = 79% chance of find two such changes. If we assume that the first change found would be the easier of the two changes to find, it is easy to imagine that the chance of finding the harder of the two might be a bit lower, given the time limits of a trial. If that chance were reduced to 79%, the probability of finding both would be 89% × 79% = 70%. The details of two-target performance are of some interest but are secondary to our purposes here, where the possibility of a second target existed purely to keep observers searching after having found the first.

An important finding from the present experiment that is discrepant with the findings of Experiments 1 and 2 is that repeated search was not faster than the initial search in the no-object-memory trials. Unlike in the previous experiments, we found that memory for scenes without explicit memory for the target object was insufficient to guide repeated search. One possible explanation is that maintaining a first target in working memory while searching for a second can proactively interfere with the subsequent memory trace for other parts of the scenes (Adamo et al., 2013; Cain et al., 2013; Cain & Mitroff, 2013), which might potentially be useful for future searches. Another possible explanation of the absence of the benefit effect is that the change detection task simply never ended with success on one-change trials in this experiment, unlike in Experiments 1 and 2; there was always the possibility of a second change. To summarize, the possible effects of target detection and continued search on implicit memory raise a lot of intriguing questions that will require further exploration.

## Experiment 4

Experiments 1–3 dealt with incidental LTM for scenes and for changes in those scenes two weeks after an initial search for changes in the scenes. Although we observed that this memory can survive a two-week delay to some degree, an important question debated in the literature is how strong incidental traces are relative to intentional memory traces (Brockmole & Henderson, 2006; Castelhano & Henderson, 2005; Draschkow et al., 2014; Hollingworth, 2004, 2005, 2006a, b; Hollingworth & Henderson, 2002; Hout & Goldinger, 2010; Tatler & Tatler, 2013). In Experiment 4, we asked whether intentional/explicit memorization of scenes and objects would influence subsequent recognition of those scenes and search for changes in their objects.

### Method

#### Participants

In total, 23 students at the Higher School of Economics (20 female, three male; mean age 19 years old) took part in the experiment for extra course credit. All reported having normal or corrected-to-normal visual acuity and no neurological problems. All participants signed informed consent before the beginning of the experiment.

#### Stimuli

The stimuli were exactly the same as in Experiment 1.

#### Procedure

**Study phase** During the study phase, participants were exposed to 64 images. On each trial, one image was presented repeatedly in the "flicker" fashion of Experiment 1, but no changes occurred in these images. The flicker rate was the same as in Experiment 1, and the total duration of each trial was 10 s. This provided a fixed encoding time for each image, ruling out any potential confounds between memorization and the difficulty of subsequent change detection.

Participants were instructed to look at an image during the entire period of its presentation and attempt to memorize it in as much detail as possible. They were told that they would be asked about the scenes and objects two weeks later.

**Test phase** The second phase of the experiment, conducted two weeks after the first, was organized in a manner similar to that in Experiment 1. A total of 96 images, including 64 old and 32 new images, were presented. Because the initial task was memorization rather than search for changes, the test questions were slightly different. For the scene memory test, when old images were presented, the participants were always presented with a modified version of an image they had seen during the study phase. They were explicitly told that, if this was an old image, one detail had been changed from the study phase. Participants were asked (1) to determine whether this was an old or a new scene and (2) to click on the change location if they identified the change (or to press the space bar if they considered the image to be a new or if they had no idea of the nature of the change). After these two responses, observers performed a search for the change in the usual alternating string of images.

#### Measures and data analysis

The measures were exactly the same as in Experiment 1. However, only data from the test phase were analyzed, since there was no report in the study phase.

### Results and discussion

Of the 23 participants, all arrived at the test phase, so all of the data were included in the analysis. In all, 12.9% of the trials were excluded from the analysis of search times in the test phase because participants failed to detect a change. However, those trials were included in the analysis of recognition and recall.

#### Memory for scenes and changes

In the test of recognition memory for scenes, participants had on average 71.3% ($SD$ = 18.2%) hits and 12.2% ($SD$ = 13.0%) false alarms, which corresponded to $A'$ = .87 ($SD$ = .08). For change recall memory, we observed the following distribution of reports among old scenes: 28.7% ($SD$ = 18.2%) for no scene memory, 67.9% ($SD$ = 16.4%) for scene memory with no object memory, and 3.3% ($SD$ = 4.5) for full memory.

#### Search for changes

In Experiment 4 there were only 3.3% full-memory reports. These were not enough to provide reliable statistics, so the corresponding trials were not included in the analysis of search times. (Recall that "full memory" in this experiment consisted of the more difficult task of noticing a change in an image two weeks after having seen the original, not merely remembering a change from two weeks before.) A one-way ANOVA was run to estimate the effect of memory on the time required to find the change (three conditions: no scene memory for old images, no object memory, and new scenes). The

ANOVA model included the observer's identity as a random factor, to handle individual differences between participants. The effect of memory on the search times was nonsignificant [$F(2, 72) = 0.53$, $p = .590$, $\eta_p^2 = .015$]. The mean search times were 6.9 s ($SD = 7.86$) in no-scene-memory trials, 7.63 s ($SD = 7.58$) in no-object-memory trials, and 7.52 s ($SD = 7.94$) in new trials. Thus, we found no evidence that prior intentional memorization of scenes affected subsequent search for changes in those scenes.

## General analysis of memory performance in Experiments 1–4

To estimate how the task performed during the study stage affected long-term memory for both scenes and changes in those scenes, we analyzed the performance in memory tests across all four experiments (Table 1).

For scene recognition memory, we performed one-way ANOVAs estimating the effect of experiment on hit rates, false alarm rates, and $A'$ values. Variations across experiments were shown to be nonsignificant for hit rates [$F(3, 76) = 0.74$, $p = .531$, $\eta_p^2 = .028$], false alarm rates [$F(3, 76) = 1.29$, $p = .285$, $\eta_p^2 = .048$], and $A'$ [$F(3, 76) = 0.39$, $p = .791$, $\eta_p^2 = .015$]. Thus, the task performed by the observers in the study phase (search for changes or intentional memorization) did not markedly alter the recognition rates.

To estimate the effect of the task performed in the study phase on the overall memory for changes in scenes, we ran a 3 × 4 (Memory Level [no scene memory, no object memory, or full memory] × Experiment [1, 2, 3, or 4]) ANOVA. Note that for Experiment 3, only the data from trials in which changes were present in the study phase were included in the analysis on no-object-memory and full-memory conditions, as these were the only trials on which participants could have any memory of a change. The main effect of memory level was highly significant [$F(2, 75) = 202.26$, $p < .001$, $\eta_p^2 = .844$], indicating different proportions of responses in the three memory levels. The main effect of experiment was nonsignificant [$F(3, 76) = 2.67$, $p = .053$, $\eta_p^2 = .095$]. The Memory Level × Experiment effect was highly significant [$F(6, 152) = 10.53$, $p < .001$, $\eta_p^2 = .294$]. Post-hoc tests showed that in general the proportion of no-object-memory reports in Experiment 4 was higher than in Experiments 1–3 ($p < .01$, Bonferroni-corrected), and the proportion of full-memory responses in Experiment 4 was substantially lower than in Experiments 1–3 ($p < .01$, Bonferroni-corrected). In general, these results show that the ability to store information about a changing object is better if the prior task was search for changes rather than intentional memorization.

Our analysis showed that in all experiments, the scene recognition rate did not change. Note that in Experiments 1–3 our participants only searched for changes and had no intention to memorize the scenes. However, their recognition memory turned out to be no worse than that of the participants in Experiment 4, who had been instructed to memorize the scenes. Moreover, we found that people who searched for changes in general showed better memory for those changes than did people who just memorized objects during the study phase and had no information about the changes. Below we will discuss these findings from a theoretical viewpoint.

## General discussion

In four experiments, we investigated the long-term consequences of searching for change on memory for those changes and for the scene contexts of those changes. Change detection is a task highly demanding of both memory and attention. In the absence of a transient marking a change, one cannot find a change without attending to a changing object (Rensink et al., 1997). Moreover, the observer needs to store information about the object in memory in order to compare it with the postchange object state (Luck & Vogel, 1997). This would be particularly true if a long interval (e.g., two weeks) intervened between the pre- and postchange views, as in Experiment 4. What do these experiments tell us about the interaction of recognition memory and change detection over a two-week interval?

### Effects on recognition memory

We used two different tasks to form memories—change detection (Exps. 1–3) and intentional memorization (Exp. 4). For purposes of the recognition memory task, the tasks represent two different classes of encoding processes—incidental and intentional/explicit. It might seem intuitive that intentional memorization should lead to a more robust and massive trace than whatever incidental memorization might occur during a nonmemory, change detection task (Saltzman & Atkinson, 1954). However, it could be suggested that the more difficult change detection task would produce deeper processing and, perhaps, better recognition memory (Craik & Lockhart, 1972; Craik & Tulving, 1975). In fact, our manipulations produced little or no effect on recognition memory for scenes (see Table 1). Apparently, the incidental task produced scene memories as effectively as intentional memorization. After two weeks, the accuracy of recognition following incidental memorization was comparable to previously reported values for intentional memorization at similar delays (Nickerson, 1968; Shepard, 1967). It was also comparable to the efficiency of immediate retrieval of scenes whose categorical distinctiveness during the study was low (Konkle et al., 2010). Of course, comparisons with other work should be made with caution, since there were differences in many of the aspects of both the study and test phases (such as the number of

**Table 1** Summary of memory performance indexes across Experiments 1–4

| | Exp. 1 | | Exp. 2 | | Exp. 3 | | Exp. 4 | |
|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Scene recognition: | | | | | | | | |
| Hit, % | 67.2 | 17.9 | 63.9 | 14.3 | 66.7 | 14.3 | 71.3 | 18.2 |
| False alarm, % | 15.2 | 8.7 | 12.8 | 11.3 | 7.6 | 13.9 | 12.2 | 13.0 |
| *A′* | .85 | .07 | .84 | .08 | .87 | .15 | .87 | .08 |
| Memory level: | | | | | | | | |
| No memory, % | 32.8 | 17.9 | 36.1 | 14.3 | 33.2 | 14.3 | 28.7 | 18.2 |
| No object, % | 40.9 | 12.3 | 46.7 | 13.1 | 52.1 | 12.3 | 67.9 | 16.4 |
| Full memory, % | 26.3 | 12.4 | 17.2 | 12.5 | 14.7 | 6.4 | 3.3 | 4.5 |

studied images, the exposure duration, use of "yes/no" ["old/new"] vs. two-alternative forced choice reports, etc.). Nevertheless, incidental memory for scenes was shown to be substantial in these experiments.

When objects were changed and those changes were detected, the resulting incidental memory for those objects was superior to memory for the same objects when observers were asked to intentionally memorize them along with many other objects. A somewhat similar result was reported by Draschkow et al. (2014) in a study comparing visual search in scenes to intentional memorization of those scenes. They found that objects looked for as targets in the visual search task were recalled better than the same objects when they were intentionally memorized. Notably, in their study the advantage of incidental recall was found only for objects embedded in meaningful scenes, not in random layouts. More broadly, this effect could reflect a general tendency for the task relevance of a target to add to the priority of that object in memory relative to other objects (Janzen & van Turennout, 2004; Thomas & Williams, 2014; Williams, 2010; Williams, Henderson, & Zacks, 2005).

It is surprising that the percentage of intentionally memorized changed targets recalled was so low (~3%, Exp. 4). In other situations, the large capacity and fidelity of LTM reported for isolated objects (Brady et al., 2008) or for objects in scenes (Castelhano & Henderson, 2005) does not fall so dramatically over time (Andermane & Bowers, 2015; Gehring et al., 1976). Even Draschkow et al. (2014), who tested free-recall memory, reported a recall probability of ~10%–20% for intentionally studied objects. There are many possible reasons for this difference. The first is the delay: It is possible that an ability to *recall* a memorized object within a scene context degrades with time, and that the degradation of this capability is greater than degradation of the ability to *recognize* the object. Second, even though we controlled for the opportunity to attend to a target (i.e., the exposure durations were the same in Exps. 1 and 4), we did not test whether observers had actually attended to the targets. Alternatively, it is possible that, when asked to recall the change, observers used an extremely conservative decision rule. According to this rule, they might have abandoned that task quickly. Unless the change was detected in that brief time, they would simply report no memory for the change. Thus, more prechange representations might have been preserved, but the postchange states were not reported because observers quit the "pre–post" comparison before they found a new object. In addition to this, some prechange object memories that were not recalled might have been recalled if they had been directly probed in the manner of Simons et al. (2002). Even given this possibility, our results show that objects once found and encoded as targets are retrieved more readily without direct cues than are the same objects studied during intentional memorization. These issues can be addressed in the future research.

Another point mentioned above that deserves special discussion, in light of the links between visual search and LTM, is our finding that observers who engaged in change detection in the study phase showed very poor memory for images in the test phase if those images had allowed them to find the change quickly in the study phase. In Experiment 2, we ruled out the explanation that mere exposure duration was what affected the memory trace. Rather, it is more likely that scene memorization is predicted better by the duration of active search for a change. It appears that effective encoding of information about the scene stopped after the task-relevant action (e.g., change detection) had ended. Subsequent passive looking seems to have had no effect on encoding. The results of Experiment 3 supported this "depth-of-processing" account. That experiment demonstrated that finding a change led to better scene recognition in the test phase, as would be predicted, since target detection is supposed to be accompanied by deeper processing due to focused attention and working memory (Luck & Vogel, 1997; Rensink et al., 1997). This conclusion builds on prior conclusions about LTM formation during visual search for objects or for changes in those objects (e.g., Brockmole & Henderson, 2006; Hollingworth, 2006b; Hollingworth & Henderson, 2002).

## Effects on repeated change detection

In our change detection experiments (Exps. 1–3), we analyzed how memory traces, created during initial search in the study phase, affected repeated search two weeks later. In all experiments, we found clear evidence that repeated search for a change becomes very rapid and efficient if the observer has explicit memory of that change. This result is obvious enough. The more interesting aspect of these results is the finding that change detection is faster when observers are searching for a change that they have searched for previously but seem to have forgotten. In the no-object-memory trials of Experiments 1 and 2, observers found a change more quickly two weeks after they had located the change for the first time, even though they had no explicit recollection of that first time. It is interesting that this effect went away in Experiment 3, in which observers were never sure that they were finished after finding one change. A possible explanation might be that along with general memory for the scene, observers must have some memory for particular objects. For example, they might recall the wrong object as a target, but that item might be related to the actual target (e.g., a window in a palace rather than a pillar of that palace). Alternatively, observers might remember the wrong instance of the correct object (e.g., recalling one zebra in the herd even if another zebra had actually changed). In that case, even if the observer discovered that the initial object was not a target, he or she could still find the change relatively efficiently by examining a limited set of candidate objects. For example, even having failed to recall the specific pillar, the observer might still focus search on the palace's façade and successfully ignore adjacent bushes and tourists. Another way to facilitate the efficiency of repeated search would be to have some memory for those objects that are definitely not targets. It is possible that these memories were rather shallow and, hence, unstable (Craik & Lockhart, 1972), in contrast to the deep explicit memory for targets. Their instability could potentially explain the lack of a search speed benefit in the no-object-memory trials of Experiment 3, in which the formation of these shallow, unstable memories could be eliminated by maintaining the target in working memory or by continued search (see the discussion in Exp. 3). To test whether these strategies were actually used in the repeated search, other methods would be needed that could be implemented in future research. For instance, comparing the eyetracking patterns in initial and repeated searches might shed some light on the mechanisms of memory guidance (e.g., Võ & Wolfe, 2012).

Finally, in no-scene-memory trials we found no facilitation of repeated search in comparison with initial searches (Exps. 1 and 2). Recall that the scenes that produced no scene memory were mostly scenes that had produced quick, easy search for change during the study phase. One could propose that search for change two weeks later was no faster because of a floor effect in the easy search trials. However, it is clear that this is incorrect, because search for change was much faster if observers explicitly recalled the change. Instead, we suggest that in the absence of any explicit memory of either the scene or the target in the scene, repeated search for a change is not memory-guided. In line with previous data (Kunar et al., 2008; Oliva et al., 2004), we suggest that observers tend to run their repeated search from the initial "ignorant" point, which seems to be a good strategy when no reliable memory is available and the search is not demanding. This conclusion might appear to contradict some previous findings, such as the contextual-cueing effect (Chun & Jiang, 1998), in which repeated search for the same target in the same scenes (or layouts) can be speeded even in the absence of explicit memory of those scenes. We do not doubt the existence of the standard contextual-cueing result. Rather, we assume that the difference in outcomes reflects important differences between the paradigms used in contextual-cueing studies and in the present study. One such difference is the delay between the initial and repeated searches. Although long-term implicit effects of repeated layouts have been documented when tested within about a week (Chun & Jiang, 2003; Jiang, Song, & Rigas, 2005), they might fail to survive a longer delay, such as that used in our study. Moreover, the long-lasting contextual-cueing effects that have been described were produced by multiple context repetitions during the study phase (Chun & Jiang, 2003). It is not clear that such effects can be reliably produced after a single trial, as in our experiments. Note also that, in no-scene-memory trials, our observers failed to freely remember either a scene or a target change. In the contextual-cueing paradigm, a target item is specified in advance by the task instructions. It is possible, therefore, that an implicitly learned context is capable of facilitating search only when combined with an explicit target template (Vickery, King, & Jiang, 2005).

In Experiment 4, simply trying to memorize the image did not make change detection faster than change detection for a new image. This result is in line with the finding pf Võ and Wolfe (2012) that repeated visual search for objects in scenes only benefits from a preview that includes search for the target objects. Neither intentional memorization nor direct fixation on those objects (while searching for superimposed letter targets) improved repeated search in that study. Seemingly, the act of completing a successful change detection task is what produces a useful, if implicit, memory for the change.

## Conclusion

To summarize, the results of our study showed that quite strong and long-lived memories can be formed during active visual search for changes. In some cases we remember both the scene and the change, rendering subsequent change detection trivial. In other cases we can successfully remember the scenes in which the changes occurred, but do not recall the specific change. This scene memory can still survive over a two-week period and support improved change detection when the unremembered change is searched for at a later date. Intentional study of objects does not produce a change detection benefit. Rather, it is search for changes that generates usable memories for changing objects that we can retrieve later and use efficiently to search for those changes a second time.

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