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Visual long-term memory and change blindness: Different effects of pre- and post-change information on one-shot change detection using meaningless geometric objects

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ABSTRACT

To clarify the relationship between visual long-term memory (VLTM) and online visual processing, we investigated whether and how VLTM involuntarily affects the performance of a one-shot change detection task using images consisting of six meaningless geometric objects. In the study phase, participants observed pre-change (Experiment 1), post-change (Experiment 2), or both pre- and post-change (Experiment 3) images appearing in the subsequent change detection phase. In the change detection phase, one object always changed between pre- and post-change images and participants reported which object was changed. Results showed that VLTM of pre-change images enhanced the performance of change detection, while that of post-change images decreased accuracy. Prior exposure to both pre- and post-change images did not influence performance. These results indicate that pre-change information plays an important role in change detection, and that information in VLTM related to the current task does not always have a positive effect on performance.

1. Introduction

We often fail to detect changes in visual scenes when the changes occur during a brief visual interruption such as an eye blink, insertion of a blank screen, or appearance of some other disruption (Levin, Simons, Angelone, & Chabris, 2002; O'Regan, Deubel, Clark, & Rensink, 2000; O'Regan, Rensink, & Clark, 1999; Rensink, O'Regan, & Clark, 1997; Simons, 1996; Simons & Levin, 1998). This phenomenon is referred to as change blindness (CB). For example, Rensink, O'Regan, and Clark (1997) used the flicker paradigm and participants observed pre- and post-change images repeatedly presented with a blank screen between them. It was demonstrated that changes went unnoticed for a long time, even though they were considerable. Poor change detection is incompatible with our belief that we can perceive the visual details of the surrounding environment. Based on CB, researchers have suggested that visual representations might contain very little information (O'Regan, 1992; O'Regan & Noë, 2001; Rensink, 2000, 2002; Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1997).

On the other hand, many studies have provided evidence that CB does not necessarily mean that visual representations are fragile (Angelone, Levin, & Simons, 2003; Beck, Peterson, & Angelone, 2007; Beck & van Lamsweerde, 2011; Busch, 2013; Hollingworth, 2005; Hollingworth & Henderson, 2002; Mitroff, Simons, & Levin, 2004; Silverman & Mack, 2006; Simons, Chabris, Schnur, & Levin, 2002; Varakin & Levin, 2006; Yeh & Yang, 2008, 2009). For example, Angelone et al. (2003) reported

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that visual representations of pre-change stimuli could be formed and maintained even when there was a failure in change detection. In addition, it has been shown that participants can detect a change implicitly even when they have failed to detect it explicitly (Hayhoe, Bensinger, & Ballard, 1998; Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2002; Hollingworth, Williams, & Henderson, 2001; Williams & Simons, 2000).

In accordance with these findings, Hollingworth (2005) demonstrated that detailed visual information could be retained long-term using a simple change detection task. In his study, participants first observed pre-change images. Then, after 24 h, they were presented with post-change images and asked to detect the difference between the two images. The ability to detect the change remained above chance, indicating that visual information valuable for change detection was represented in visual long-term memory (VLTM). Recent studies directly examining the capacity of VLTM found that observers could memorize detailed visual information for thousands of objects and scenes (Brady, Konkle, Alvarez, & Oliva, 2008; Konkle, Brady, Alvarez, & Oliva, 2010a, 2010b). Furthermore, it also has been demonstrated that visual object representations can be formed involuntarily (Castelhano & Henderson, 2005; Williams, Henderson, & Zacks, 2005). A more recent study has shown that visual representations of unfamiliar faces could be maintained after 7 weeks, even though participants had only observed the stimuli for a few seconds under the incidental condition (Nishiyama & Terasawa, 2013).

Considering these results, it is possible that content in VLTM unconsciously affects online visual processing. It has been shown that participants' visual experiences affect the performance of change detection (Beck, Angelone, & Levin, 2004; Beck et al., 2007; Jackson & Raymond, 2008; Reingold, Charness, Pomplun, & Stampe, 2001; Takahashi & Watanabe, 2008; Werner & Thies, 2000). For example, Werner and Thies (2000) demonstrated that experts could detect a change related to their specialized field easier than can novices. Additionally, studies on contextual cueing (Chun & Jiang, 1998) have shown that performing identical trials repeatedly can enhance subsequent change detection (Droll, Gigone, & Hayhoe, 2007; Jiang & Song, 2005). Although these studies suggest that VLTM automatically influences the performance of change detection, how VLTM contributes to online visual processing is still not completely understood. Is the task-relevant information retained in VLTM always used involuntarily during visual processing? If so, does the visual information always have positive effects on the performance of the current task? The goal of the present study was to elucidate these questions using the change detection task.

Vierck and Kiesel (2008) manipulated the presentation times of images in the flicker paradigm, and demonstrated that the repetitive presentations of pre- and post-change images improved the performance of change detection. Although this result indicates that visual information accumulated while performing the task could be used in change detection, the effect of VLTM on change detection was not clarified. The procedure used by Vierck and Kiesel (2008) could not distinguish between the effects of VLTM and visual short-term memory (VSTM), because the repetitions of images were presented immediately before the change. However, the authors argued that the positive effect on performance was based mainly on VSTM. In addition, Jiang and Song (2005) demonstrated that change detection becomes easier when performing identical trials repeatedly. This indicates that the configuration of items in each trial is learned while participants engage in the change detection task, and the visual information stored in VLTM involuntarily affects the change detection that follows. However, in Jiang and Song's (2005) procedure, the effect of visual information retained in VLTM was unclear, because performing identical change detection trials repeatedly might itself have a positive effect on performance of the next trial. Moreover, as the participants observed both the pre- and post-change images repeatedly, how the specific information stored in VLTM (i.e., pre- or post-change information) had an effect on change detection performance was not revealed. To clarify these uncertain points, we used an independent study phase prior to the change detection task and investigated directly whether and how VLTM involuntarily affects the subsequent change detection. In the study phase, participants observed pre-change images in Experiment 1, and post-change images in Experiment 2, and these appeared in half of the trials of the subsequent change detection task. Our procedure allowed us to investigate the effect of specific visual representations maintained in VLTM on change detection. Finally, in Experiment 3, we tested the additional effects of VLTM of both pre- and post-change images on change detection.

In our study, we used a one-shot change detection task (e.g., Simons, 1996) to exactly control the presentation times of images. In the one-shot change detection task, participants observe pre- and post-change images once with a brief blank screen in between and are asked to detect the change. It has been proposed that CB occurs because of the failure to encode and/or retain the pre-change representation (e.g., Beck & Levin, 2003; Becker & Pashler, 2002; Brady, Konkle, Oliva, & Alvarez, 2009; O'Regan & Noë, 2001; Rensink, O'Regan, & Clark, 1997), the failure to retrieve the pre-change representation, or the failure to compare the pre- and post-change information (e.g., Angelone et al., 2003; Busch, 2013; Hollingworth, 2003; Mitroff et al., 2004; Simons et al., 2002). These studies suggest that enhancing the availability of pre-change information will have positive effects on performance of the subsequent change detection. Thus, if the visual representations of pre-change images maintained in VLTM are available for the subsequent change detection involuntarily, they should improve the performance of change detection.

On the other hand, VLTM of post-change images might have a different effect on change detection. It has been reported that performance on memory tests for post-change objects is often more accurate than that of pre-change objects (e.g., Beck & Levin, 2003; Mitroff et al., 2004). In order to explain the degradation of memory for pre-change objects, Yang and Yeh (2009) demonstrated that post-change information interrupts the retrieval of pre-change information because of the greater accessibility of post-change representations (i.e., blocking). This indicates that CB may be partly induced by the retrieval interference of post-change information. If post-change information stored in VLTM interferes with the retrieval of pre-change information, it should have a negative effect on subsequent change detection. Therefore, it is possible that VLTM