Is a pre-change object representation weakened under correct detection of a change? ☆

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ABSTRACT

We investigated whether a pre-change representation is inhibited or weakened under correct change detection. Two arrays of six objects were rapidly presented for change detection in three experiments. After detection, the perceptual identification of degraded stimuli was tested in Experiments 1 and 2. The weakening of a pre-change representation was not observed under correct detection. The repetition priming effect was observed for a pre-change object and the magnitude was equivalent to the effect for a post-change object. Under change blindness, repetition priming for a pre-change representation was observed when detection did not require report of location in Experiment 1 and was not observed when location was required to be reported in Experiment 2. The results of Experiment 3 showed that a pre-change representation was recognized at a higher rate under correct detection than under change blindness, reflecting a stronger rather than a weaker pre-change representation in the former context.

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1. Introduction

Change blindness refers to a phenomenon where people fail to detect a change in the visual environment. This phenomenon has raised debates over the existence of internal representation (see Noe, 2005; Simons & Rensink, 2005 for discussion) and how detailed the internal representation might be (Hollingworth, 2006). Researchers have also investigated the causes of change blindness (see Rensink, 2002; Simons, 2000 for reviews). Volatile representation caused by overwriting (Beck & Levin, 2003) and by disengagement of attention (Rensink, O'Regan, & Clark, 2000) is one of the multiple factors that can lead to change blindness.

While researchers of previous studies on change blindness have debated the nature of representation under change blindness, a recent study shows that correct change detection may also weaken the internal representation (Silverman & Mack, 2006). Using a perceptual identification task, Silverman and Mack (2006) did not observe the repetition priming effect for a pre-change stimulus that was replaced by a post-change stimulus and also for an unchanged stimulus that remained the same between two displays. The repetition priming effect refers to performance enhancement for previously viewed stimuli in comparison with performance based on new stimuli when participants do not intentionally recollect the previous stimuli (e.g., Feustel, Shiffrin, & Salasoo, 1983; Jacoby & Dallas, 1981). Retrieval intentionality in memory judgment is a criterion used to distinguish implicit from explicit memory (McDermott, 2000; Schacter, Bowers, & Booker, 1989). The dissociation

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between the priming effect and recognition memory that requires intentional recollection has been observed in both normal participants (Jacoby & Dallas, 1981; Tulving, Schacter, & Stark, 1982) and amnesic patients (Cohen & Squire, 1980; Hamann & Squire, 1997). The study of repetition priming has also been conducted to reveal the mechanisms that govern implicit memory (Stark & McClelland, 2000). On the basis of the null finding of the priming effect, Silverman and Mack (2006) proposed an inhibition/attenuation hypothesis.

Silverman and Mack (2006) stated the following:

“...it seems possible that when change is detected, the visual system, in an effort to protect the changed input and maximize change detection, inhibits all the other stimulus information in the arrays or attenuates it so effectively that it is unable to compete with the changed stimulus representation...” (p. 424).

As “conscious perception of change requires focused attention” (Silverman & Mack, 2006, p. 409), their intriguing finding implies that the stimulus in focal attention inhibits stimuli that are not currently focused in attention under correct detection. That is, conscious awareness of a change can inhibit or weaken the representations of other stimuli. Conscious awareness of a change is operationally defined as the ability to detect the change between two stimuli in the visual environment. This phenomenon can find its counterparts in other attention phenomena, such as negative priming (Tipper, 1985) and inhibition of return (Posner & Cohen, 1984). Negative priming results from the inhibition of ignored distractors to protect target processing; inhibition of return reflects inhibition of the previously attended location after the attention is disengaged. Selective attention reduces the competition from other stimuli by facilitating visual processing of the target stimuli and inhibiting the processing of the stimuli irrelevant to the behavioral goal (Desimone, 1998; Desimone & Duncan, 1995).

However, it is unclear for two reasons why a pre-change representation should be inhibited or weakened under correct detection. First, the pre-change representation is relevant to the behavioral goal. Second, the pre-change representation is not a competitor against the post-change stimulus in the decision process. Evidence from negative priming studies has shown that strong competition is a pre-requisite for observing the inhibition of the ignored distractor (Grison & Strayer, 2001; Malley & Strayer, 1995). Moreover, inconsistent results have been observed in two studies that investigated the pre-change representation under change blindness and under correct detection (Silverman & Mack, 2006; Yeh & Yang, 2008).

The finding of inhibition of a pre-change representation under correct detection has important implications for understanding the relationship between conscious awareness and the representations of other stimuli that are processed prior to the state of visual awareness. If the representation of a pre-change or unchanged stimulus is indeed inhibited or weakened under correct detection, the entity in focal attention may degrade other information in mental representation that was previously viewed. The investigation of the context under which such inhibition occurs should shed some light on the relationship between current visual awareness and the representations of prior encounters.

The purpose of the present study is to investigate whether a pre-change representation is inhibited or weakened under correct change detection. Methodological differences exist between the two studies that showed inconsistent results (Silverman & Mack, 2006; Yeh & Yang, 2008), even though both used a perceptual identification task to examine a pre-change representation in the context of change detection. It is likely that these differences have caused inconsistent findings. Using a methodology similar to that of Silverman and Mack (2006), we investigated the existence and the nature of a pre-change object representation in the context of change detection.

2. Experiment 1

The two studies that found inconsistent results differed in methodology. Silverman and Mack (2006) in their key experiment presented a 3×3 letter array for a short duration (100 ms) on each trial. A gray field followed for 80 ms before the second array was shown for another 100 ms. Participants detected whether there was any change in the letter array and the row where one, two, or three letters may have been changed. Participants then identified a degraded trigram. In contrast, Yeh and Yang (2008) presented the two arrays for a long duration (2000 ms) with a blank interval of 350 ms between the two arrays. In the perceptual identification task, an undegraded object stimulus was presented with increasing viewing duration until a vocal response was made. As identification of fragmented pictures (Weldon & Roediger, 1987) and picture naming (Mitchell & Brown, 1988) are two examples used in testing implicit memory (see Toth, 2000), we used the perceptual identification of degraded stimuli in this experiment as adopted by Silverman and Mack (2006). We modified the method used by Yeh and Yang (2008), using rapid stimulus presentation for change detection. According to the inhibition/attenuation hypothesis, participants should inhibit or weaken a pre-change representation when they consciously detect a change and hence need to protect the post-change object in the focus of attention. Repetition priming for the pre-change representation would not be observed under correct detection in contrast to identifying a new stimulus.

2.1. Method

2.1.1. Participants

Eighteen undergraduate students at National Taiwan University participated in this one-hour experiment. They received a bonus credit for an introductory psychology course for their participation. They were all age 18–21 years old with normal or corrected-to-normal vision.

2.1.2. Equipment

A PC with a 3.40-GHz Intel Pentium IV processor was used to run the experiment. The display monitor was a 17-in. color monitor with a vertical refresh rate of 75 Hz. E-Prime (Schneider, Eschman, & Zuccolotto, 2002) was used to run the experiment.

2.1.3. Stimuli and design

Similar to the previous study (Yeh & Yang, 2008), three hundred twelve color images from the CorelDraw v5.0 (Corel-DRAW!, 1994) art library were used as object stimuli. Each object was converted to a 24-level color scale and sized to a maximum of 120 pixels on both the *x* and *y* dimensions. Each object subtended a visual angle of 5.24° (horizontal) $\times$ 4.29° (vertical) at the viewing distance of approximately 60 cm. Six stimuli were randomly placed around an imagery circle with a radius of 7.01° on each trial. A white background was used throughout the trial. Only one object in the array changed in the change trials, with a post-change object replacing a pre-change object. Following the method used in Experiment 2 by Beck and Levin (2003), the post-change array was horizontally shifted by a visual angle of 1.95° to prevent participants from relying on the transient changes of luminance in display to detect changes. There was no blank interval between the pre- and post-change arrays.

Three versions of 240 experimental trials were constructed, one half were change trials and the other half were no-change trials. In the change trials, pairs of visually and conceptually dissimilar pre- and post-change objects were first selected to prevent inter-object facilitation or interference in encoding. Visual similarity was defined as similarity in color, size, shape, orientation, or a combination of these attributes. Conceptual similarity was defined as categorical or functional similarity. These definitions were provided to 63 participants who were asked to rate the objects on the two types of similarities. For the pairs used in this experiment, the mean rating of visual similarity was 1.35 ($SE = 0.05$) and the mean rating of conceptual similarity was 1.25 ($SE = 0.04$) on a 7-point Likert scale. The unchanged objects in each change trial were then randomly selected from 310 objects of the stimulus set. The stimuli in the no-change trials were randomly selected from 312 stimuli. Each object image was rotated as the pre-change, post-change, and old stimulus across the three versions so that the results would not reflect item-specific effects.

Participants performed an object identification task after the change detection task on each trial. Similar to the method used in Silverman and Mack's (2006) study, degraded stimuli were used in the identification task by superimposing a 50% random-dot mask on each object for identification. Following a change trial, the object to be identified was one of the four types of objects: an old unchanged object in the visual displays, the pre-change object, the post-change object, and a new unseen object. There were 30 observations of each type. Following a no-change trial, there were only two types of objects to be identified: unchanged old object and a new object with 60 observations in each type. The frequency of each type was equivalent and the order of the types was randomized.

2.1.4. Procedure

Five practice trials were run so that participants became familiar with the tasks. Throughout the trial, at the beginning of each block, participants were reminded to recite "1 2 3 4 5" to suppress verbal rehearsal until the probe display was shown (see Fig. 1). After viewing a fixation cross for 1 s, the pre-change display was presented for 180 ms and followed by a post-change display for duration of 180 ms. A mask display consisting of six Mondrian patterns was then presented for 180 ms to mask the post-change stimuli. A blank display was then presented for 1 s during which the participants decided whether there was any change. They pressed the numeric key '1' for a no-change decision and the key '2' for a change decision. Accuracy, rather than speed, was emphasized in the change detection task.

An identification task was then tested. Participants were required to name a degraded object as accurately and as quickly as possible. Vocal responses triggered a voice key that recorded the reaction time in identification while the experimenter recorded the accuracy. Either the basic object type (e.g., a dog) or a subordinate exemplar (e.g., a golden retriever) was accepted as a correct answer. If participants named the object at the superordinate level (e.g., animal) or incorrectly named the object, the response was coded as an error.

2.2. Results

2.2.1. Change detection

The detection sensitivity A' was computed with the formula determined by whether the hits were higher (Grier, 1971) or lower (Aaronsen & Watts, 1987) than the false alarms. The values of A' range from .5 (chance) to 1.0 (perfect sensitivity). The mean proportion correct detection was .73 ($SE = .04$) and the mean detection sensitivity A' was .88 ($SE = .01$).

2.2.2. Object identification

The number of observations under change blindness was sparse for some participants because they showed high proportion of correct change detection (greater than .80). To obtain reliable performance measures, we used a criterion of having at least five observations in every cell to include participants in further data analysis as used in a previous study (Yeh & Yang, 2008). The identification performance under correct detection and under detection failure was analyzed separately by using a one-way (types of objects) repeated measures analysis of variance (ANOVA). Table 1 presents the mean performance data.

Fig. 1. The trial procedure used in Experiment 1. Two arrays of six objects were rapidly displayed for the participants to report whether there was any change between the two arrays. Participants then performed a perceptual identification task.

Table 1

Mean performance and standard deviations of Experiment 1.

		Pre-change	Post-change	Old unchanged	New
<i>(n = 11)</i>					
		Under detection failure			
Proportion correct	<i>M</i>	.86	.89	.95	.83
	<i>SD</i>	.12	.12	.05	.16
Reaction time	<i>M</i>	1226.82	1244.59	1210.45	1477.05
	<i>SD</i>	260.56	296.30	269.22	320.78
<i>(n = 18)</i>					
		Under correct detection			
Proportion correct	<i>M</i>	.88	.83	.94	.80
	<i>SD</i>	.11	.11	.07	.16
Reaction time	<i>M</i>	1141.09	1127.68	1097.82	1335.45
	<i>SD</i>	188.57	347.77	168.48	264.20

2.2.3. Object identification under correct detection

All the participants' data were analyzed. On identification accuracy, the main effect of object type was significant [$F(3,51) = 11.70$, $p < .01$, $\eta_p^2 = .41$]. In planned comparisons, the accuracy in identifying an old unchanged object [$F(1,51) = 34.73$, $p < .01$, $\eta_p^2 = .41$], a pre-change object [$F(1,51) = 7.47$, $p < .01$, $\eta_p^2 = .13$], and a post-change object [$F(1,51) = 5.86$, $p < .05$, $\eta_p^2 = .10$] was higher than that in identifying a new object. The repetition priming effect was observed for all three objects.

For reaction time (RT), the main effect of object type was significant [$F(3,51) = 4.15$, $p < .05$, $\eta_p^2 = .20$]. In planned comparisons, the RT in identifying an old unchanged object [$F(1,51) = 9.56$, $p < .01$, $\eta_p^2 = .16$], a pre-change object [$F(1,51) = 4.10$, $p < .05$, $\eta_p^2 = .07$], and a post-change object [$F(1,51) = 9.12$, $p < .01$, $\eta_p^2 = .15$] was faster than that in identifying a new unseen object. Under correct detection, the repetition priming effects for the pre-change object, the post-change object, and an old unchanged object were all observed. The identification speed for the three objects was not significantly different ($p > .1$).

2.2.4. Object identification under detection failure

Eleven participants' data were analyzed. For identification accuracy, the main effect of object type was not significant ($p > .05$). For the RT data, the main effect of object type was significant [$F(3,30) = 3.11$, $p < .05$, $\eta_p^2 = .24$]. In planned comparisons, the RT in identifying a pre-change object [$F(1,30) = 6.17$, $p < .05$, $\eta_p^2 = .17$], a post-change object [$F(1,30) = 5.32$, $p < .05$, $\eta_p^2 = .15$], and an old unchanged object [$F(1,30) = 7.00$, $p < .05$, $\eta_p^2 = .19$] was faster than that in identifying a new object. Under detection failure, the repetition priming effects for a pre-change object, a post-change object, and an old unchanged object were all observed in the RT data. There were no significant differences ($p > .1$) in the speed of identifying these three objects.

2.3. Discussion

We replicated Yeh and Yang's (2008) results using a short viewing duration of visual arrays for change detection and degraded stimuli for perceptual identification. The repetition priming effect for the pre-change objects was observed under both correct detection and detection failure. The level of the representation was comparable whether the participants consciously noticed the change (correct detection) or not (detection failure).¹ The post-change object did not inhibit a pre-change object under correct detection. The level of implicit representation for a pre-change object was equivalent to the level for a post-change object, as identification speed was not significantly different between the two types.

In this experiment, the duration of the pre-change displays was 180 ms to mimic the brief presentation of stimuli used in Silverman and Mack's (2006) study. However, the results were inconsistent with their findings. Another difference existed in the methodology: their participants were required to report the row in a 3×3 matrix of letters where a change had occurred. It is likely that in this task context, participants needed to protect the post-change representation in focal attention for correct change detection. We examined this possibility in Experiment 2.

3. Experiment 2

The objective of this experiment was to examine whether a pre-change representation is inhibited or weakened under correct detection when the location information is required in the decision. Participants in this experiment were asked to report the exact change location when they detected a change. We examined whether this task context could cause a pre-change representation to be inhibited or weakened under correct detection.

3.1. Method

3.1.1. Participants

Twenty-five undergraduate students at National Taiwan University participated in a one-hour experiment. They received a bonus credit for an introductory psychology course for their participation. They were all ages 18–21 years old with normal or corrected-to-normal vision.

3.1.2. Stimuli, design, and procedure

The stimuli, design, and experimental procedure were the same as those used in Experiment 1 except that participants were asked to report the exact change location when they detected a change. After the Mondrian mask display, a display was provided that showed '1', '2', '3', '4', '5', and '6' on object positions for the participants to detect a change. Participants pressed the space bar for a no-change decision and pressed the corresponding numeric key for indicating where a change had occurred. This allowed us to examine whether the explicit retrieval of change location can alter the pre-change representations.

3.2. Results

3.2.1. Change detection

A response was coded as a correct answer when participants correctly reported the change location in the change trials. The mean accuracy of change detection was .57 ($SE = .05$), and the mean detection sensitivity A' was .82 ($SE = .03$). A cross-comparison with Experiment 1 was conducted by a one-way between-subject ANOVA. The results showed that the experiment effect approached significance on the proportion correct [$F(1,41) = 4.21, p < .06, \eta_p^2 = .09$] and showed a trend on the sensitivity [$F(1,41) = 2.61, p < .1, \eta_p^2 = .06$], with worse performance in this experiment than in Experiment 1.

3.2.2. Object identification

We used the same criterion as in Experiment 1 to include participants in further data analysis. Data from 17 participants were available under detection failure; data from 18 participants were available under correct detection. The identification performance under correct detection and detection failure were analyzed separately using a one-way repeated measures ANOVA, with object type as the single variable. Table 2 presents the mean performance data.

3.2.3. Object identification under correct detection

For identification accuracy, the main effect of the object type was marginally significant [$F(3,51) = 2.74, p = .05, \eta_p^2 = .14$]. In planned comparisons, the accuracy in identifying an old unchanged object was higher than that in identifying a new object [$F(1,51) = 5.69, p < .05, \eta_p^2 = .10$], whereas there were no significant differences ($p > .1$) in identification accuracy between a new object and either a pre-change or a post-change object.

¹ Item analyses were conducted to evaluate whether the findings could have resulted from specific items. No item-specific effects were observed. In addition, matched *t*-test analyses across items showed that the difference in identification speed under correct detection and under change blindness was not significantly different from zero for the pre-change stimuli.

Table 2

Mean performance and standard deviations of Experiment 2.

		Pre-change	Post-change	Old unchanged	New
(n = 17)		Under detection failure			
Proportion correct	M	.82	.88	.93	.85
	SD	.17	.09	.07	.13
Reaction time	M	1281.00	1207.65	1205.24	1360.65
	SD	279.70	170.56	204.33	309.06
(n = 18)		Under correct detection			
Proportion correct	M	.92	.88	.94	.88
	SD	.05	.12	.06	.12
Reaction time	M	1154.75	1160.42	1203.28	1391.53
	SD	248.55	303.33	225.25	272.19

For RT, the main effect of the object type was significant [$F(3,51) = 7.92, p < .01, \eta_p^2 = .32$]. In planned comparisons, the RT in identifying a pre-change object [$F(1,51) = 17.87, p < .01, \eta_p^2 = .26$], a post-change object [$F(1,51) = 17.03, p < .01, \eta_p^2 = .25$], and an old unchanged object [$F(1,51) = 11.30, p < .01, \eta_p^2 = .18$] was faster than that in identifying a new object. Under correct detection, the repetition priming effect for a pre-change object, a post-change object, and an old unchanged object was all observed. The identification speed for the three objects was not significantly different ($p > .1$).

3.2.4. Object identification under detection failure

For identification accuracy, the main effect of the object type was significant [$F(3,48) = 3.77, p < .05, \eta_p^2 = .19$]. In planned comparisons, the accuracy in identifying an old unchanged object was significantly higher than that in identifying a new object [$F(1,48) = 5.96, p < .05, \eta_p^2 = .11$], whereas there were no significant differences between identifying a new object and a pre-change object or between identifying a new object and a post-change object ($ps > .05$).

For RT, the main effect of object type approached significance [$F(3,48) = 2.59, p = .06, \eta_p^2 = .14$]. In planned comparisons, the RT in identifying a post-change object [$F(1,48) = 5.60, p < .05, \eta_p^2 = .26$], and an old unchanged object [$F(1,48) = 5.78, p < .05, \eta_p^2 = .27$] was faster than that in identifying a new object. Although there was a trend that RT in identifying a pre-change object (1281.00 ms) was slightly faster than that in identifying a new object (1360.65 ms), there was no significant difference between the two conditions ($p > .5$). When a change was not consciously detected, the repetition priming effect for a post-change object and an old unchanged object was observed whereas there was no repetition priming effect for a pre-change object.

3.3. Discussion

Participants in this experiment were required to report the exact change location. This task was more difficult than the same-different judgment used in Experiment 1, and thus, performance in Experiment 2 was worse than in Experiment 1. However, the results showed that when a change was successfully detected, the repetition priming effect was observed for a pre-change object, a post-change object, and an unchanged object. A pre-change object representation was not inhibited or weakened under correct detection. The reaction time in identifying a pre-change object was similar to that in identifying a post-change and an unchanged object.

The results showed the same pattern as in Experiment 1 under correct detection. Neither a pre-change representation nor an unchanged object representation was inhibited or weakened under correct detection. The results do not support the inhibition/attenuation hypothesis. Under detection failure, the repetition priming effect was also observed for an unchanged object and a post-change object as found in Experiment 1. As perceptual fluency may underlie repetition priming (Jacoby, 1983; Jacoby & Dallas, 1981), the priming effect for an unchanged object may have arisen because this object was repeated the third time in identification after being presented twice, in both the pre- and post-change displays. The priming effect for a post-change object occurred because this object representation was recently activated and fluency arose from repetition.

In contrast to the results of Experiment 1, there was no priming effect for a pre-change object under detection failure. The nature of the pre-change object representation may have caused the difference between Experiments 1 and 2 in terms of whether the repetition priming effect could be observed for a pre-change object representation under change blindness. With brief viewing, each object in a display may not be fully encoded and a pre-change object representation may be incomplete. When the incomplete representation was not attained under detection failure, re-processing of the incomplete representation could still lead to priming via fluency in Experiment 1. In Experiment 2, participants were required to report the location where a change had occurred. The participants must encode the object-location conjunction and hence allocate less resource to process the perceptual properties of each object. As a result, each incomplete representation was even more fragmented. When the fragmented representation was not attained under detection failure, re-processing did not lead to perceptual fluency and the priming effect did not manifest. We investigated in Experiment 3 the nature of a pre-change representation under change blindness with a direct test.

4. Experiment 3

On the basis of the results of Experiment 2, we postulated that brief viewing led to an incomplete representation for each object in the pre-change display in Experiment 1. It is likely that the equivalent priming effect between a pre-change and a post-change representation under correct detection resulted from a floor effect so that the effect was insensitive to subtle differences between two incomplete representations. Thus, converging evidence is needed to corroborate the argument that the pre-change representation is not inhibited or weakened under correct detection.

We used a direct test of memory that requires intentional access to internal representations. In a traditional two-alternative forced choice test (2AFC), participants are required to judge which stimulus is the previously viewed item on each trial. As participants must intentionally recollect the previous encounters to select the correct response, recognition performance results from conscious use of memory representation. If a pre-change representation is inhibited or weakened only when participants are consciously aware of the change (Silverman & Mack, 2006), intentional access to a pre-change representation should be more difficult under correct detection than under detection failure. However, previous findings based on long stimulus duration (Beck & Levin, 2003; Mitroff, Simons, & Levin, 2004; Yeh & Yang, 2008) have shown that recognition of a pre-change object was better under correct detection than under detection failure. We examined recognition performance using rapid stimulus presentation.

The second objective was to verify that a pre-change representation under rapid presentation is indeed incomplete. Yeh and Yang (2008) have demonstrated that the similarity between a pre- and post-change object improved the recognition of a near-intact pre-change object representation and the similarity benefits were not observed when a pre-change object was masked and was not fully encoded. Therefore, we examined the similarity effect. Similarity benefits would not be observed if an unmasked pre-change representation is incomplete. Regardless of the incompleteness, a pre-change representation must have been re-activated, accessed, and compared with the post-change representation for correct detection. Thus, we expected that recognition performance of a pre-change representation under correct detection is better rather than worse in comparison with recognition under detection failure. If the results support the prediction, a pre-change representation can be accessed in consciousness to a greater extent (Beck & Levin, 2003; Mitroff et al., 2004; Yeh & Yang, 2008) under correct detection than under detection failure. If a pre-change representation is inhibited or weakened in focused attention under correct detection (Silverman & Mack, 2006), conscious use of the representation should be more difficult in this context than in the context of detection failure.

4.1. Method

4.1.1. Participants

Eighteen undergraduate students at National Taiwan University participated in this one-hour experiment. They received a bonus credit for an introductory psychology course for their participation. They were all ages 18 to 22 years old with normal or corrected-to-normal vision.

4.1.2. Stimuli and design

The stimuli and design were similar to the ones used in Yeh and Yang's (2008) study. There were four categories of object types defined by the relationship between a pre- and post-change object: (1) visually and conceptually dissimilar as used in Experiments 1 and 2, (2) visually similar and conceptually dissimilar (visual similarity: 3.07 ± 0.16 ; conceptual similarity: 1.24 ± 0.19), (3) visually dissimilar and conceptually similar (visual similarity: 2.52 ± 0.10 ; conceptual similarity: 5.04 ± 0.10), and (4) visually and conceptually similar (visual similarity: 4.61 ± 0.10 ; conceptual similarity: 5.26 ± 0.08).

Three-hundred sixty experimental trials were constructed, with a 2:1 ratio between the change and no-change trials. Among the 240 change trials, half consisted of the condition where the pre- and post-change objects do not share any similarities in order to balance the ratio of similar to dissimilar pairs. There were 40 trials in each of the three categories where the pre- and post-change objects shared similarity in visual, conceptual, or both properties.

Participants performed two 2AFC recognition tests after change detection, with the first one testing the pre-change object and the second testing the post-change object in that trial (referred to as pre-2AFC and post-2AFC). After a no-change trial, unchanged objects were randomly selected from the six stimuli for the two recognition tests. After a change trial, the pre- and post-change objects were used for the two corresponding tests. The distractors in the recognition tests were selected to be visually and conceptually different from the target in order to prevent potential interference effects on decision making.

4.1.3. Procedure

The procedure was the same as in Experiment 1 except that the object identification task was substituted with two 2AFC recognition memory tests. The Pre-2AFC was always tested before the Post-2AFC so that post-change recognition would not contaminate the pre-change recognition. Participants were required to choose the targets that were presented in the pre- and post-change displays. Accuracy, rather than speed, was emphasized in the recognition and change detection task.

4.2. Results

4.2.1. Change detection

Table 3 shows the mean performance and detection sensitivity A' in each condition. A 2 (visual similarity) $\times$ 2 (conceptual similarity) repeated measures ANOVA was conducted to analyze the proportion correct and the detection sensitivity. As the pattern of results was similar, we only presented the results based on detection sensitivity. The main effect of visual similarity was significant [$F(1, 17) = 134.43, p < .01, \eta_p^2 = .89$]. The mean detection sensitivity (.76) was significantly lower when the pre- and post-change objects shared visual similarity than when they did not share visual similarity (.83). The main effect of conceptual similarity was also significant [$F(1, 17) = 5.67, p < .05, \eta_p^2 = .25$]. The mean detection sensitivity was significantly lower when the pre- and post-change objects shared conceptual similarity (.78) than when they did not share conceptual similarity (.80). Replicating previous findings (Yeh & Yang, 2008), the results showed that both the visual and conceptual similarity degraded the detection performance. The interaction between visual similarity and conceptual similarity did not reach the significance ($p > .05$).

4.2.2. Recognition memory

We used the same criterion as used in Experiments 1 and 2 to include participants in further data analysis such that there were at least 5 observations in every cell. Data from 14 participants were available under detection failure; data from 16 participants were available under correct detection. Table 4 presents the mean performance data for both the pre- and post-change recognition. We focused on the recognition of a pre-change object, as the nature of the post-change object is not the issue of investigation. Performance under correct detection and detection failure was analyzed separately by using a 2 (visual similarity) $\times$ 2 (conceptual similarity) repeated measures ANOVA.

4.2.3. Recognition under detection failure

The results did not show any significant effect ($ps > .3$). Moreover, pre-change recognition under detection failure was not above the chance level ($p > .05$) and participants could not use the similarity between the pre- and post-change objects to improve recognition of a pre-change object.

4.2.4. Recognition under correct detection

The results showed a significant main effect of visual similarity [$F(1, 15) = 5.90, p < .05, \eta_p^2 = .28$], with better recognition when the pre- and post-change shared visual similarity (.76) than when the two were dissimilar (.66). The main effect of conceptual similarity was also significant [$F(1, 15) = 7.40, p < .05, \eta_p^2 = .33$], with better recognition when the pre- and post-change shared conceptual similarity (.74) than when the two were dissimilar (.67). The interaction was not significant ($p > .5$).

4.2.5. Comparing recognition performance under detection failure and under correct detection

Only 10 participants had sufficient observations in all the conditions for this analysis. The results from a 2 (detection accuracy) $\times$ 2 (visual similarity) $\times$ 2 (conceptual similarity) repeated measures ANOVA showed a significant main effect of detection accuracy [$F(1, 9) = 22.40, p < .01, \eta_p^2 = .71$], with higher accuracy under correct detection (.71 $\pm$.02) than under

Table 3

Mean performance and standard deviations in change detection observed in Experiment 3. VD: visually dissimilar, VS: visually similar, CD: conceptually dissimilar, CS: conceptually similar.

(n = 18)	VD		VS	
	CD	CS	CD	CS
Hits	.73 (.12)	.65 (.16)	.53 (.15)	.48 (.12)
A'	.84 (.11)	.82 (.08)	.76 (.11)	.75 (.08)

Table 4

Mean performance and standard deviations (in parenthesis) in recognition memory observed in Experiment 3. VD: visually dissimilar, VS: visually similar, CD: conceptually dissimilar, CS: conceptually similar.

		Under detection failure (n = 14)				Under correct detection (n = 16)			
		VD		VS		VD		VS	
		CD	CS	CD	CS	CD	CS	CD	CS
Pre-2AFC	M	.49	.50	.50	.55	.62	.71	.73	.78
	SD	.12	.18	.14	.12	.08	.16	.19	.15
Post-2AFC	M	.59	.67	.68	.72	.83	.88	.85	.85
	SD	.10	.24	.16	.17	.11	.12	.13	.15

detection failure ($.50 \pm .03$). The effect of visual similarity was significant under correct detection when the pre- and post-change objects did not share conceptual similarity [$F(1,36) = 5.46, p < .05, \eta_p^2 = .13$]. The effect of conceptual similarity approached significance under correct detection when the pre- and post-change objects did not share visual similarity [$F(1,36) = 3.84, p < .06, \eta_p^2 = .10$].

4.3. Discussion

The results support the idea that brief viewing leads to incomplete object representations. When an incomplete pre-change representation was not attained in change detection, the conscious use of this incomplete representation was difficult. The recognition performance under detection failure was at a chance level and the similarity in the pre- and post-change objects did not improve recognition. Considering the priming effect observed in Experiment 1, the results also show dissociation between implicit and explicit access to an incomplete pre-change object representation under detection failure. We used the criterion of intentionality (McDermott, 2000) to distinguish implicit and explicit access.

The results are inconsistent with the prediction of the inhibition/attenuation hypothesis. Recognition of a pre-change object was better under correct detection than under detection failure. Consistent with the previous findings (Beck & Levin, 2003; Mitroff et al., 2004; Yeh & Yang, 2008), the level of conscious access to a pre-change object representation is higher under correct detection than under detection failure as shown by the better performance in intentional recollection. Participants must have formed a pre-change representation, re-activated the representation, and compared it with the post-change object for a successful change decision. With better access to a pre-change object representation under correct detection, pre-change recognition was above the chance level and the similarity between the pre- and post-change objects also improved recognition. The trace strength of a pre-change representation was stronger under correct detection than under detection failure to provide better recognition.

5. General discussion

We used rapid stimulus presentation to examine whether a pre-change object representation is inhibited or weakened under correct change detection as suggested by the inhibition/attenuation hypothesis (Silverman & Mack, 2006). The results of Experiment 1 showed that repetition priming of a pre-change representation was observed in perceptual identification under both correct detection and detection failure. In addition, the priming effect was equivalent to the priming effect of a post-change representation. According to the inhibition/attenuation hypothesis, repetition priming should be observed only for a post-change representation when participants correctly detect a change. In Experiment 2, participants were required to report the location where a change had occurred prior to performing the identification task. The results replicated those of Experiment 1 under correct detection, but repetition priming of a pre-change representation was not observed under detection failure.

In Experiment 3, recognition that requires intentional remembering was used to investigate the nature of a pre-change representation based on rapid presentation and the conscious attainment of the representation. According to the inhibition/attenuation hypothesis, a pre-change representation is inhibited or weakened only under correct detection and not under change blindness. Pre-change recognition should be more difficult in the former than the latter context. The results showed chance-level recognition under detection failure and similarity with the post-change object could not improve performance. In contrast, recognition of a pre-change object under correct detection was above the chance level and the similarity of the pre-change object with the post-change object improved pre-change recognition. The results showed better conscious access to a pre-change representation under correct detection than under detection failure.

5.1. Object representations of briefly viewed stimuli under correct detection

The results of the three experiments described above do not support the inhibition/attenuation hypothesis. Repetition priming effects were observed for a pre-change object representation under correct detection in both Experiments 1 and 2. Moreover, the magnitude of the priming effect was equivalent to the priming effect for a post-change object. After brief viewing, a pre-change object representation was not inhibited or weakened under correct detection.

Given that the experimental context in Experiment 2 was highly similar to the one used in the study by Silverman and Mack (2006), it is plausible that the inconsistent results arose from the use of different stimulus materials and also the probe used in the perceptual identification test.² Silverman and Mack (2006) presented a 3×3 matrix of letters and each letter was relatively small with a visual angle of $0.6^\circ \times 0.45^\circ$. In addition, degraded trigrams were presented in perceptual identification and all the letters in a trigram must be reported in the correct serial positions to be accepted as a correct response. Perceptual identification of degraded small and similar letters may have led to conjunction errors resulting from combining the features of the test probe and the features of the sparse representations. As a result, their participants inhibited or attenuated the pre-change and unchanged letters. In contrast, unrelated object pairs were used in the present experimental context and the size

² An ideal study would include experiments using letter stimuli. A pilot experiment adopting the same methodology except for using a longer inter-stimulus interval between the pre- and post-change arrays did not replicate Silverman and Mack's (2006) findings. Further exploration for the causes is needed.

of each object was relatively large with an angle of $5.24^\circ \times 4.29^\circ$. Also, only one degraded stimulus was presented in perceptual identification. Confusion errors may have been less in integrating features of a degraded test probe and a pre-change representation. As a result, repetition priming of a pre-change representation was observed under correct detection.

The use of a matrix by Silverman and Mack (2006) may also facilitate grouping of simple letters. Given that attention must focus on the item level rather than on the row or column of grouped letters for change detection, suppression of the whole may be necessary as the whole may compete with the processing of individual letters. As letter stimuli are easily confused and suffer interference from other letter stimuli, inhibition may be activated to protect the post-change letters.³ Inhibition of a pre-change stimulus may be necessary when simple stimuli are arranged to encourage grouping while confusion arises from their similarity. No such inhibition is necessary when complex objects are presented, as confusion among objects and grouping of individuated object is unlikely. Inhibition of a pre-change stimulus is contingent upon the stimulus context.

5.2. Object representations of briefly viewed stimuli under change blindness

Under detection failure, repetition priming of a pre-change representation was observed only in Experiment 1 and not in Experiment 2. The null finding in Experiment 2 is also different from those observed by Silverman and Mack (2006). They found repetition priming of a pre-change representation under detection failure. Given that it should be more difficult to observe repetition priming of trigrams, we considered the difference in the coding scheme as a possible cause for observing different results. Silverman and Mack (2006) included both miss (i.e., unable to report the change) and false alarm (i.e., reported a change in a row that had not changed) trials as detection failure. Only miss trials were used in the present study. Future research is needed to resolve the inconsistent results.

The results of the present study suggested that object representations were incomplete when participants viewed two arrays of six objects presented briefly for change detection. The representations were further degraded when participants must allocate resources to encode object-location conjunction. Despite the incompleteness, repetition priming for a pre-change representation can be observed under detection failure in Experiment 1. In contrast, the results of Experiment 3 showed that recognition of an incomplete pre-change representation was at a chance level and the similarity with the post-change object could not improve recognition under detection failure. Indirect and direct tests of memory dissociate.

Yeh and Yang (2008) used both the priming effect in identification and the presence of similarity benefits on the pre-change recognition to argue for a near-intact representation in the experimental context where two arrays of six objects were each presented for 2000 ms for change detection. The results showed equivalent priming effects for a pre-change object under detection failure and under correct detection, suggesting that the level of representation was similar in the two contexts. A recognition test was conducted in another experiment and the results showed that the similarity between the pre- and post-change objects improved pre-change recognition under detection failure. More importantly, the similarity benefit was observed only when the objects in the pre-change display were not masked. When a 20% random-dot mask was superimposed on every object in the pre-change display, there was no similarity benefit on the pre-change recognition under detection failure.

The absence of the similarity benefits on the pre-change recognition under detection failure was replicated in Experiment 3 of the present study with a brief presentation of unmasked pre-change arrays. In addition, the pre-change recognition under detection failure was at the chance level. An incomplete pre-change representation can support repetition priming. Yet, conscious access to an incomplete pre-change representation was difficult. While previous studies (Angelone, Levin, & Simons, 2003; Hollingworth, Williams, & Henderson, 2001; Ryan & Cohen, 2004; Silverman & Mack, 2006; Simons, Chabris, Schnur, & Levin, 2002; Yeh & Yang, 2008) have demonstrated the dissociation between change detection and memory performance, the present study is the first to demonstrate the dissociation between indirect and direct tests of memory for a pre-change object representation.

Two factors may have caused the dissociation observed in the present study. Snodgrass and Hirshman (1994) showed that a match between study and test line-drawing objects affects recognition. Recognition was more accurate when the two stimuli were matched in the degree of fragmentation than when the two were mismatched. The mismatch between an incomplete object representation and an intact test probe may have reduced the familiarity in recognition. Another possibility was that recognition familiarity relied on conceptual fluency (Wagner & Gabrieli, 1998). With brief viewing, it was unlikely that participants could encode every object to the conceptual level. When participants failed to re-activate a pre-change representation under change blindness, the probability for the conceptual property to support conceptual fluency was low. Either or both factors may have produced a chance-level pre-change recognition performance. In contrast, the perceptual property of an incomplete pre-change representation can still support repetition priming in identification through perceptual fluency.

The results support the view that multiple factors can lead to change blindness (Simons, 2000; Simons & Rensink, 2005) and change blindness does not necessarily reflect the absence of a detailed pre-change representation (Hollingworth, 2006). Change blindness can occur because of retrieval and comparison failure (Hollingworth, 2003; Mitroff et al., 2004), decision difficulty (Wilken & Ma, 2004; Yeh & Yang, 2008; Zelinsky, 2003), or retrieval blocking of a pre-change representation (Yang & Yeh, 2008). The internal representation under change blindness can be on a continuum from near-intact (Yeh & Yang,

³ We thank R. Rensink and D. Simons for suggesting these two possible reasons.

2008) to sparse (the present study; Simons & Rensink, 2005), depending on the degree of processing of the details of a representation. When the representation is incomplete, conscious use of the representation (Simons & Rensink, 2005) can be difficult as shown in the results of Experiment 3. Even a similar post-change object cannot enhance pre-change recognition. The dissociation between the indirect and direct tests of memory for a pre-change representation suggests that converging evidence is necessary to reveal the nature of a pre-change representation under change blindness.

6. Conclusion

We investigated whether a pre-change representation is inhibited or weakened under correct change detection. The results from three experiments are inconsistent with the prediction based on the inhibition/attenuation hypothesis (Silverman & Mack, 2006). Even at a rapid presentation rate, a pre-change representation under correct detection could support repetition priming in perceptual identification and could be better accessed in intentional remembering. More importantly, the magnitude of the priming effect was equivalent to the priming effect for a post-change object. The level of representation, reflected by the priming effect, was comparable between a pre- and post-change representation under correct detection. Under change blindness, an incomplete pre-change representation led to repetition priming when the object-location bound representation was not necessary in the decision. Also, the accuracy of conscious use of the pre-change representation was similar to that of chance. The implicit memory and the explicit memory of a pre-change representation dissociated under change blindness. Converging evidence from multiple approaches is necessary to better understand the nature of the pre-change representation in the context of change detection.

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