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Memory for recently accessed visual attribute

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Abstract

Recent reports suggest that the attended features of an item may be rapidly forgotten once they are no longer relevant for an ongoing task (attribute amnesia). This finding relies on a surprise memory procedure that places high demands on declarative memory. Here we used inter-trial priming to examine whether the representation of an item's identity is lost completely once it becomes task irrelevant. If it is, then the identity of a target on one trial should not influence performance on the next trial. In three experiments we replicated the finding that a target's identity is poorly recognized in a surprise memory test. However, we also observed location and identity repetition priming across consecutive trials. These data suggest that, although explicit recognition on a surprise memory test may be impaired, some information about a particular target's identity can be retained after it is no longer needed for a task.

Introduction

How much of the visual world do we remember from one moment to the next? Two findings emerge from past research. First, memory is better for attended stimuli than ignored stimuli, and second, consciously inaccessible stimuli may nevertheless influence task performance. An example of the first finding comes from Rock and Gutman's (1981) study on shape memory. Participants viewed overlapping red and green outline shapes and rated the aesthetic appeal of the shapes in one color. In a surprise memory test, participants were able to reliably identify the attended, but not the ignored, shapes as ones they had seen during the rating task. Poor explicit recognition of unattended shapes, however, does not mean that participants have no memory of the shapes. Using stimuli similar to Rock and Gutman's, DeSchepper and Treisman (1996) showed that ignoring a shape on one trial impairs one's ability to identify it on a subsequent trial (negative priming). Negative priming was observed even when several hundred trials separated the initial exposure from subsequent testing. Summarizing related findings in their book entitled "Inattentional blindness," Mack and Rock (1998) concluded that there was no conscious perception without attention. Others placed the locus of inattention in memory rather than perception, suggesting that our inability to report ignored information reflects a memory failure, a form of "inattentional amnesia" (Wolfe, 1999).

The flip side of inattentional blindness/amnesia is the robust representation of attended information. For example, when tracking a subset of moving objects, people can report where the tracked (attended) objects are (Alvarez & Oliva, 2008) and their shapes (Horowitz et al., 2007). Attended stimuli, however, may be rapidly forgotten if they are no longer needed for a task. For example, in "directed forgetting" tasks, participants forget materials they just encoded to memory when instructed to by the experimenter (Basden, Basden, & Gargano, 1993). In one demonstration of poor memory for recently attended verbal material, Craik and Watkins (1973) presented participants with a list of words and asked them to attend to words that started with a specific letter, such as the letter D. The list paused periodically for participants to report the last D word. In this design, all D words were attended to, but earlier ones became irrelevant when participants encountered a new D word. Subsequently, participants showed poor recognition of attended but displaced words. These findings indicate that maintaining durable representations of encoded stimuli may depend, in part, on their continued relevance to an ongoing task.

Because daily activities are often accompanied by changes in task goals and priorities, most attended stimuli may have only fleeting representations. A striking demonstration of this possibility came from recent reports on "attribute amnesia" (Chen & Wyble, 2015a, 2015b). In one experiment, participants viewed a briefly presented array of digits. Their task was to report the location of a target digit, such as the odd number presented among even numbers. After performing the localization task many times, participants received a surprise question probing the target's identity. Despite having just accessed the target's identity, participants frequently failed to report its identity. Although other studies have demonstrated that recently ignored visual input is poorly remembered (Chabris & Simons, 2011; Mack & Rock, 1998), Chen and Wyble's findings show that this phenomenon occurs for recently attended, and presumably, consciously accessed information.

Attribute amnesia raises questions about the durability of mental representations for recently attended information. One possibility is that as soon as the target's identity is no longer useful for the task, its representation is lost. Rapid forgetting of irrelevant information may be adaptive, as maintaining more than what is needed not only clutters memory but also increases distractibility (Koutstaal, 2011). However, it is also possible that recently accessed, but irrelevant, target information continues to be represented in a form that is less accessible and more fragile than representations of currently relevant information. Memory tests that require explicit reporting, such as the surprise memory test used by Chen and Wyble (2015a, 2015b), may not be effective in uncovering these representations. Procedures capable of detecting weaker or implicit memory traces may be needed.

To examine the durability of mental representations for a recently accessed visual attribute, we conducted three experiments using Chen and Wyble's (2015a) procedure. Crucially, we measured memory for a recently accessed visual attribute using both the surprise memory test and inter-trial priming. Visual search studies showed that participants are faster if the target on the current trial is the same as the target on the preceding trial. Inter-trial priming is observed in feature search (Maljkovic & Nakayama, 1994) and conjunction search tasks (Kristjánsson, Wang, & Nakayama, 2002). Priming occurs for the visual attribute that defines the target (e.g., color in a color search task), but not for irrelevant attributes (e.g., shape in a color search task; Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004). Because priming is detected across trials, it reflects a sustained memory representation for the attended attribute. However, although inter-trial priming has been found with briefly presented and masked stimuli (e.g., Sigurdardottir, Kristjánsson, & Driver, 2008), we are not aware of any studies that assessed inter-trial priming using Chen and Wyble (2015a, 2015b)'s task.

In this study we replicated Chen and Wyble's (2015a) experimental conditions but evaluated inter-trial priming as well. Of interest is whether inter-trial priming occurs for the same attribute that people are unable to report in the surprise memory test. The lack of priming would bolster the claim that recently accessed attributes are forgotten immediately, once they are irrelevant for task performance. The presence of priming would suggest that recently accessed attributes leave a durable memory trace, even though the trace may not be adequate for answering the surprise memory question.

Method

Participants. A pre-specified sample size of 20 was used in each experiment to match the sample size used in Chen and Wyble (2015a). There were 12 females and 8 males in Experiment 1, 14 females and 6 males in Experiment 2, and 15 females and 5 males in Experiment 3. All participants were students at the University of Minnesota with normal or corrected-to-normal visual acuity and normal color vision. They were between 18-28 years old and were naïve to the purpose of the study. Each participant completed one experiment.

Equipment. Participants were tested individually in a room with normal interior lighting. They sat at an unrestrained distance of approximately 40cm from a CRT monitor (refresh rate 75Hz; resolution 1024x768 pixels). Experiments were programmed with Psychtoolbox (Brainard, 1997; Pelli, 1997) implemented in MATLAB (www.mathworks.com).

Design and materials. Experiment 1 was similar to the second experiment in Chen and Wyble (2015a). We simplified the surprise memory procedure by asking only about the target's identity and location, not its color. Similar to Chen and Wyble (2015a), the search display was presented for 250ms before being replaced by a mask display. We set the eccentricity of each search item to 6.25°, with the intent to match the eccentricity used in Chen and Wyble (2015a). However, we later found that we had misinterpreted Chen and Wyble's method, as they had presented stimuli at an eccentricity of 4.4°. The difference in eccentricity increased task difficulty in Experiment 1, relative to Chen and Wyble (2015a). We therefore performed two replications. Experiment 2 used the same eccentricity as Experiment 1 (6.25°) but increased the duration of the search display to 500ms. Experiment 3 used the same eccentricity (4.4°) and the same display duration (250ms) as Chen and Wyble (2015a).

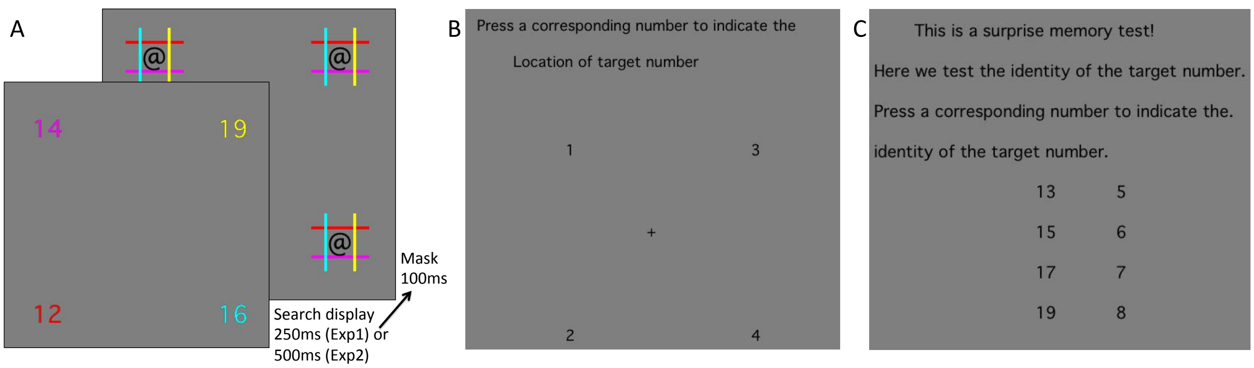

Figure 1. A. A schematic illustration of the search display and the mask. In this example participants searched for an odd number. B. The location prompt used in Experiments 1 and 2. Participants reported the location of the target number by pressing a key corresponding to the number in the chosen location. The same prompt was used on all trials of Experiments 1-2. In Experiment 3 letters "a", "s", "d", and "f" occupied the location prompt. Which letter was in which location was randomized across trials. C. The identity prompt used on surprise and post-surprise trials in all experiments. Participants reported the identity of the target number, by pressing the key corresponding to the number on its right. This was followed by the location prompt. Stimuli were adapted from Chen and Wyble (2015a).

Following 16 trials of practice, participants performed 155 pre-surprise trials of a digit localization task. On each trial they viewed a black fixation cross (0.62°) and four black placeholder circles (0.62°) presented in a square configuration (item eccentricity 6.25° in Experiments 1 and 2, 4.4° in Experiment 3). After a variable duration of 800-1800ms, the display of four digits was presented for 250ms (Experiments 1 and 3) or 500ms (Experiment 2). A color mask then replaced each digit and was displayed for 100ms (Figure 1A). The digits had different colors – blue, yellow, red, or green - randomly assigned to the four positions. The digits were drawn from 12 to 19. For half of the participants the display contained one odd number (randomly chosen from 13, 15, 17, or 19) and three even numbers (randomly chosen from 12, 14, 16, and 18, without replacement). The task was to find the odd number and report its spatial location. For the other half of the participants, the display contained one even number (randomly chosen from 12, 14, 16, and 18) and three odd numbers (randomly chosen from 13, 15, 17, or 19, without replacement). The task was to find the even number and report its spatial location.

After the mask display and a 400ms blank display, participants were prompted to enter their response by pressing a button corresponding to the target's quadrant. In Experiments 1 and 2, participants pressed the number ("1", "2", "3", or "4") that corresponded to the indicated quadrant (Figure 1B). Which response key corresponded to which quadrant was fixed for all trials (e.g., key "1" always appeared in the upper left quadrant). Consequently, if the target appeared in the same location on consecutive trials, the key press for the correct response also repeated. To dissociate location and motor repetition in Experiment 3, the response letters "a", "s", "d", or "f" were randomly presented in the four quadrants across trials. Participants pressed the letter in the same location as the target digit. Because the letter-quadrant mapping was randomized, location repetition was dissociated from motor repetition. This manipulation led to longer RT in Experiment 3 relative to Experiments 1 and 2.

A correct response was followed by three rising tones for a total of 300ms, whereas an incorrect response received a low buzz for 200ms. The next trial then commenced with the fixation and placeholder display.

Following the pre-surprise stage, participants were given a single surprise trial (trial 156) and four post-surprise trials (trials 157-160). On these trials participants were first prompted to report the target's identity and then to report its location after the initial search array (Figure 1C). This identification prompt was unexpected during the surprise trial, but not during post-surprise trials. For participants in the "odd target" task the prompt asked them to choose the target digit from 13, 15, 17, and 19. For participants in the "even target" task the prompt asked them to choose the target digit from 12, 14, 16, and 18. Following an identification response, participants were asked to report the target digit's location. Unlike Chen and Wyble (2015a), we did not prompt participants to report the target's color, which was not recently attended to.

Table 1 summarizes the experimental parameters used in the three experiments, as well as those used in Chen and Wyble (2015a).

Table 1. Experimental parameters used in this study and those of Chen and Wyble (2015a).

Experiment	Item eccentricity	Display duration
Experiment 1	6.25°	250ms
Experiment 2	6.25°	500ms
Experiment 3	4.40°	250ms
Chen and Wyble (2015a), Experiment 2	4.40°	250ms

Results

(1) Pre-surprise localization accuracy

During the first 155 trials (the pre-surprise stage) participants localized the target digit with moderate to high accuracy. Mean accuracy was 75% in Experiment 1, 91% in Experiment 2, and 87% in Experiment 3. These were all higher than chance ($p < .001$), though accuracy differed significantly across experiments, $F(2, 57) = 37.18$, $p < .001$, $\eta_p^2 = .57$. The level of performance in Experiment 1 corresponded to a capacity of about 2 digits: Correctly identifying 2 of the four digits while guessing on the other 2 would yield an accuracy of 75%. Increasing display duration (Experiment 2) or reducing item eccentricity (Experiment 3) both enhanced localization performance.

(2) Surprise and post-surprise trials

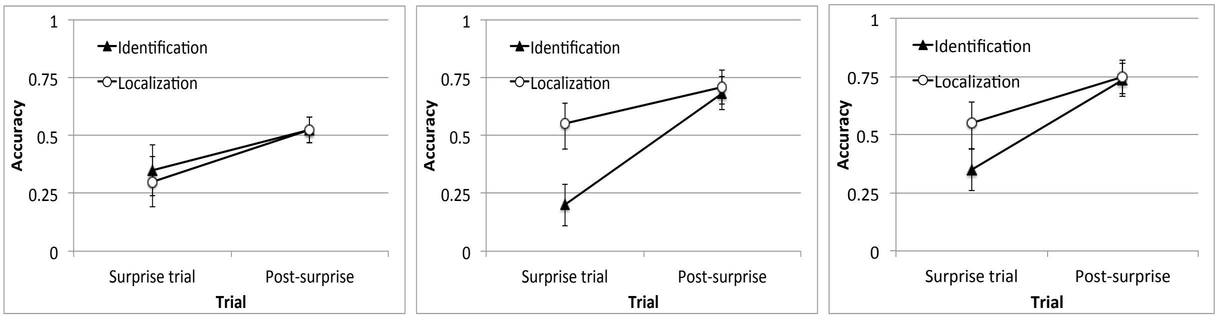

Figure 2. Results from the surprise and post-surprise trials. Error bars show ±1 S.E. of the mean. The post-surprise trials were the average of trials 157 to 160. Left: Data from Experiment 1. Middle: Data from Experiment 2. Right: Data from Experiment 3.

Figure 2 displays results from the localization and identification tests of the surprise trial and post-surprise trials, separately for each of the three experiments.

On the surprise trial, combined across all three experiments, 30% of participants successfully identified the target digit, which was not significantly higher than chance, $\chi^2(1) = 0.80$, $p > .35$. Identification of the target digit was near chance levels in all three experiments (35%, 20%, and 35%, in Experiments 1, 2, and 3, respectively), all $\chi^2(1) < 1.07$, $ps > .30$. Despite poor identification, targets were correctly localized by 47% of participants on the surprise trials across all three experiments, a value which was significantly higher than chance, $\chi^2(1) < 15.02$, $p < .001$. Chi-square tests showed that localization performance was at chance in Experiment 1 (30%, $p > .25$), but above-chance in Experiments 2 and 3 (both 55%, $p < .002$). This finding successfully replicated Chen and Wyble's (2015a) observation of "amnesia" for a recently accessed target attribute – its identity – despite better than chance performance for the target's location.

Performance on both the identification and localization tasks in the post-surprise trials improved to above-chance levels. Across participants in all experiments, post-surprise identification accuracy was 65%, and post-surprise localization accuracy was 66%. Bootstrapping based on 10,000 samples yielded 95% confidence intervals (CI) that did not include 0.25 (chance), suggesting that post-surprise performance was above chance (95% CI for identification: [57%, 72%]; 95% CI for localization: [58%, 73%]). This finding held when each experiment was examined separately.

To compare performance on pre-surprise, surprise, and post-surprise trials, and to take into consideration that these phases involved different types of data (e.g., binary on the surprise trial, continuous on the pre-surprise trials), we estimated the 95% CI for data in each phase. Bootstrapping using 10,000 samples yielded the following 95% CIs for the localization performance (N=60): pre-surprise [82%, 87%], surprise [35%, 58.3%], and post-surprise [58.3%, 72.9%]. None of the 95% CIs overlapped, suggesting that localization performance was impaired on the surprise trial relative to both the pre- and post- surprise trials, and that performance was impaired on the post-surprise trials relative to the pre-surprise trials. Similarly, identification performance was impaired on the surprise trial (95% CI: [18.3%, 41.7%]) relative to the post-surprise trials (95% CI: [57%, 72%]). Finally, to confirm the inferences drawn from the bootstrapping analyses, we performed permutation tests to examine whether observations in the three phases (pre-surprise, surprise, and post-surprise) were exchangeable. These tests showed that they were not exchangeable (all ps < .01).

(3) Inter-trial priming

The impaired localization performance on the surprise trial relative to both the pre- and post-surprise trials suggests that the surprise procedure may have been disruptive of memory. A more sensitive measure is therefore needed to assess residual memory for the digit's identity. We therefore examined inter-trial priming of the target digit's identity as well as its location. We binned trials based on (a) whether the current trial's target digit was identical to the preceding trial's target digit, and (b) whether the current trial's target was in the same location as the preceding trial's target. Because priming can only occur if participants correctly respond to the target on the preceding trial, trials that followed trials with incorrect responses were excluded in the analysis. This resulted in an average, per participant, of 73 trials in which neither location nor target identity repeated, 25 trials in which only target identity repeated, 25 trials in which only the target's location repeated, and 8 trials in which both location and identity repeated.

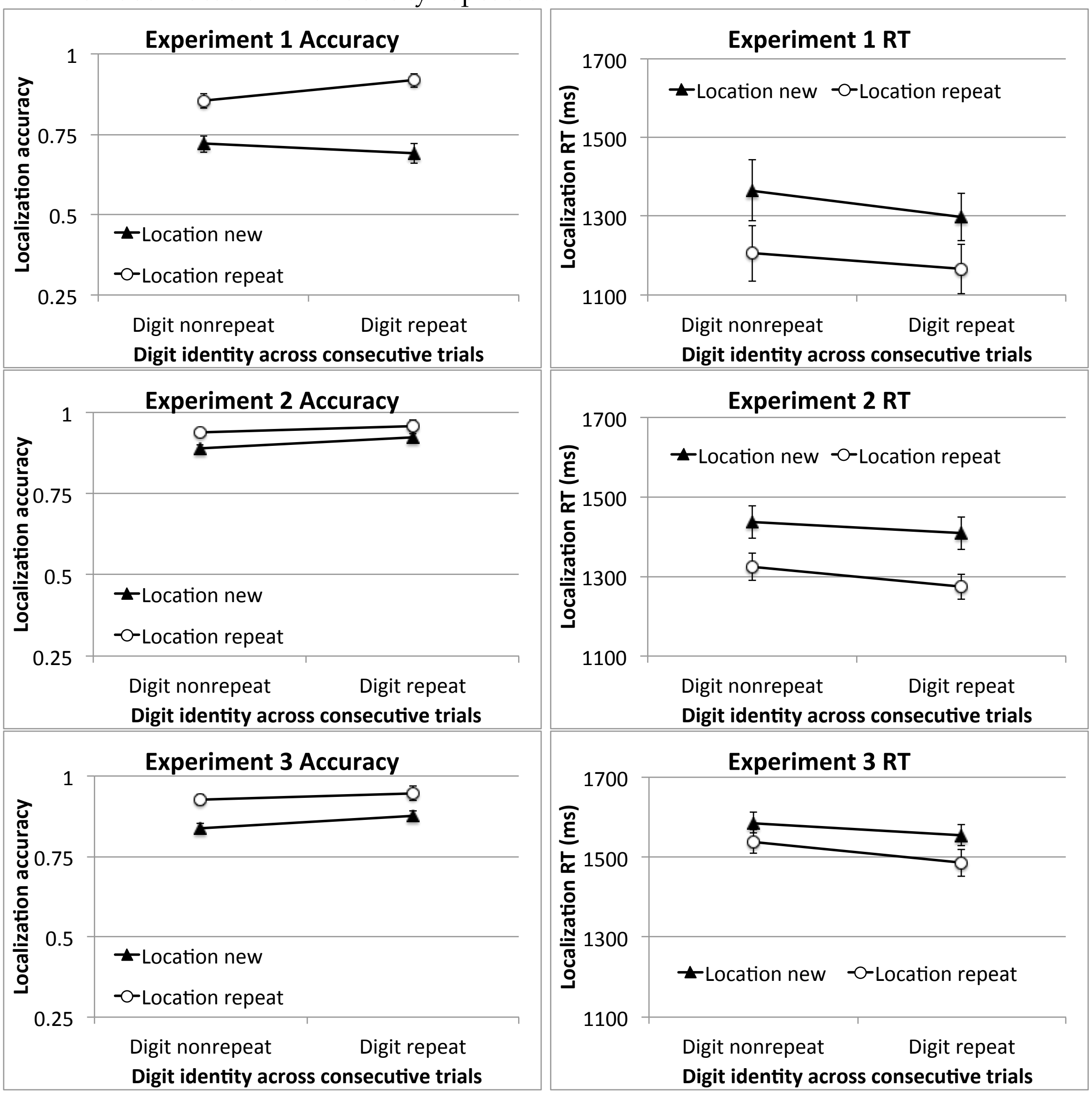

Figure 3. *Accuracy (left) and reaction time (right) data in the localization task during the pre-surprise stage. Included were data in which an accurate response was made to the preceding trial. Error bars show ±1 S.E. of the mean. Some error bars are small and may be difficult to see.*

Figure 3 shows the priming data, separately for accuracy and RT. We first report statistical analyses for the three experiments individually, and then report the combined results across all three experiments.

Repeating the target's location across consecutive trials yielded significantly higher accuracy in each experiment, $F(1, 19) = 67.79$, $p < .001$, $\eta_p^2 = .78$ in Experiment 1, $F(1, 19) = 11.93$, $p < .003$, $\eta_p^2 = .39$ in Experiment 2, and $F(1, 19) = 22.67$, $p < .001$, $\eta_p^2 = .54$ in Experiment 3. Repeating the target's identity across consecutive trials did not significantly influence accuracy in Experiment 1, $F < 1$, but facilitated accuracy in both Experiment 2 ($F(1, 19) = 6.27$, $p < .03$, $\eta_p^2 = .25$) and Experiment 3 ($F(1, 19) = 4.58$, $p < .05$, $\eta_p^2 = .19$). Experiment 1 did yield evidence of inter-trial priming of the digit identity, reflected as a significant interaction between location repetition and identity repetition, $F(1, 19) = 5.41$, $p < .05$, $\eta_p^2 = .22$. Specifically, on trials in which the target's location repeated, accuracy was higher if the target's identity repeated than when its identity changed, $t(19) = 2.51$, $p < .021$. On trials in which the target's location changed, accuracy was unaffected by whether the target's identity repeated, $t(19) < 1$. This pattern is consistent with previous studies on inter-trial priming, in which priming of one target property (e.g., orientation) was most clearly shown when the other property (e.g., color) also repeated (Hillstrom, 2000). Location and identity repetition did not interact in the other two experiments, $F < 1$.

Inter-trial priming was also evidenced in RT (incorrect trials were excluded from the RT analysis). Repeating the target's location facilitated RT in Experiment 1 ($F(1, 19) = 16.60$, $p < .001$, $\eta_p^2 = .47$), Experiment 2 ($F(1, 19) = 25.30$, $p < .001$, $\eta_p^2 = .57$), and Experiment 3 ($F(1, 19) = 12.79$, $p < .002$, $\eta_p^2 = .40$). Repeating the target's identity also facilitated RT, and this effect was statistically significant in Experiment 1 ($F(1, 19) = 13.61$, $p < .001$, $\eta_p^2 = .42$) and Experiment 2 ($F(1, 19) = 13.39$, $p < .001$, $\eta_p^2 = .41$), but not in Experiment 3, $F(1, 19) = 3.64$, $p < .072$, $\eta_p^2 = .16$ (though priming was revealed in accuracy). Location repetition and digit repetition did not interact in Experiment 1 ($F(1, 19) = 3.14$, $p > .09$), or Experiment 3 ($F < 1$), but reached significance in Experiment 2 ($F(1, 19) = 13.51$, $p < .002$, $\eta_p^2 = .42$). Specifically, identity repetition induced greater priming if the target's location also repeated (Hillstrom, 2000).

Across all 60 participants in this study, pre-surprise localization accuracy was about 2.5% higher ($F(1, 59) = 7.48$, $p < .008$, $\eta_p^2 = .11$), and RT was 72ms faster ($F(1, 59) = 27.73$, $p < .001$, $\eta_p^2 = .32$), when the target digit on trial N was identical to that on trial N-1. These data suggested that participants retained the target's identity for at least one trial.

Discussion

This study examined the durability of mental representations of recently attended visual attributes. Following Chen and Wyble's (2015a) observation of attribute amnesia, we asked whether people retain some memory of recently attended visual attributes in the absence of explicit recognition. In addition to explicitly probing memory for location and identity on surprise trials, these experiments used inter-trial priming as a way to increase sensitivity to the presence of memory for a recently attended target's attributes across trials. In three experiments, a dissociation between explicit recognition and repetition priming was observed. On surprise trials, participants were unable to report the target's identity above chance. Yet they demonstrated significant inter-trial priming of the target's identity. These findings indicate that a failure to accurately report an attribute on the surprise trials does not imply that the information is completely absent from memory.

What explains the dissociation between recognition memory and inter-trial priming of the target's identity? One possibility is that it is a classic dissociation between explicit memory and implicit memory (Gabrieli, 1998). Though recognition performance is not a pure measure of explicit memory (i.e., it can rely on a sense of familiarity, Yonelinas & Levy, 2002), successfully answering the surprise question may require highly robust explicit memory. Inter-trial priming, on the other hand, is a relatively automatic form of target memory (Maljkovic & Nakayama, 1994). Inter-trial priming has been shown to be unaffected by top-down knowledge of future trials' targets (Hillstrom, 2000; Maljkovic & Nakayama, 1994). Thus, one interpretation of our findings is that recently attended, but now irrelevant, stimuli leave an implicit memory trace in the absence of explicit memory. This interpretation would be consistent with the nature of memory for unattended stimuli. As shown by Rock and Gutman (1981) and DeSchepper and Treisman (1996), unattended stimuli may induce strong negative priming even though participants have poor explicit memory for them.

Alternatively, we need not propose separate memory systems (e.g., explicit vs. implicit memory) to explain the dissociation between recognition performance and inter-trial priming. Rather, the priming measure may simply be more sensitive than the surprise memory test. If the target's identity and location are held briefly in visual working memory, they could be cleared from working memory by the surprise memory task. Visual working memory is fragile and easily disrupted by subsequent visual input (Makovski, Shim, & Jiang, 2006; Makovski, Sussman, & Jiang, 2008; Swallow, Zacks, & Abrams, 2009). The surprise memory task was especially challenging because participants had to read the question, understand what it meant, and change their ongoing task from localization to identification. These processes require executive control and could be a strong source of memory interference (Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008). Hence, poor memory of the target's identity may reflect the disruption of working memory by the surprising events. Furthermore, the need to process the surprise question imposed long delays between the initial encoding of the digit display and the recognition response. Median RT for responding to the surprise identity question was 33 seconds, during which time participants likely engaged in many processes that potentially interfere with memory, including reading the questions and switching tasks.

Chen and Wyble (2015a) previously considered, but rejected the possibility that the surprise test may have disrupted memory. Their conclusion was based on the finding that participants remained capable of reporting the target's location on the surprise trial, suggesting that the surprise test was not detrimental in general. However, in our study, the surprise test had a general detrimental effect on memory. Localization performance was significantly lower on the surprise trial relative to both the pre- and post- surprise trials. Although participants were able to report the target's location with high accuracy on pre-surprise trials, their performance declined substantially on the surprise trial. Because the same memory procedure was used, this difference cannot be explained in terms of implicit versus explicit memory. Presumably participants would have reached high levels of accuracy if the localization task had come first on the surprise trial. The substantial drop in accuracy more likely reflects interference and memory decay following the task demands associated with interpreting and responding to the surprise identification question. The fact that localization performance on surprise trials was better than identification does not provide sufficient evidence against the possibility that the surprise memory test disrupted location memory. Instead, it suggests only that identity memory was less robust than location memory. One reason for the difference is that location continued to be relevant for the task but identity was no longer relevant.

One objection to our findings is that participants may not have had to identify the digit in pre-surprise and surprise trials. Participants could have performed the parity task by either identifying the digit (individual digit level), or by extracting shape information that distinguishes odd from even digits (category level). Chen and Wyble (2015a) assumed that individual digits were identified. Our priming data supported this assumption. If participants had only categorized the digits, for instance by extracting features present in odd digits but not in even digits, then target identity should have had no effect on performance across trials. Inter-trial priming is measured at the individual digit level, not at the category level. The presence of identity priming indicates that participants have processed the digits to the exemplar level. The priming effects demonstrated that some information about the digit identity is maintained at least some of the time. What is the nature of the maintained information? Is it the semantic meaning of the digit (e.g., "12" is an even number greater than 11 but smaller than 13), or is it surface features correlated with the digit (e.g., a constellation of features corresponding to the digit 12)? Future research is needed to address this question.

Regardless of whether the dissociation between surprise memory test and priming reflects different subsystems of memory or degrees of sensitivity, our study reveals two new findings regarding attribute amnesia. First, the surprise memory test may underestimate how much information people retain about recently attended visual attributes. A failure to correctly answer the surprise memory question shows that whatever information people do retain, it does not always survive the long delay and substantial interference from the test procedure. These factors also render it difficult to pinpoint when information about the target attributes is lost. Second, under some conditions people appear to retain information about a recently attended attribute that is no longer task relevant. Inter-trial priming of the target's identity indicates that this information is maintained for at least one trial, beyond the time implied by performance on the surprise memory test (i.e. immediately after the trial).

Conclusion

In three experiments that measure inter-trial priming and recognition memory for recently attended target attributes, we found that people could not reliably report the target's identity in a surprise memory test. This finding confirmed Chen and Wyble's report on attribute amnesia (2015a). Our study also showed, however, that the surprise memory test may have underestimated target memory. In the absence of significant recognition memory, participants may nonetheless demonstrate inter-trial priming when the target attribute repeats across trials. These findings suggest that people may have sustained mental representations for recently attended visual attributes that become task-irrelevant. Future research should examine whether the sustained memory is entirely implicit, or whether people retain conscious access to such memory.

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