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Encoding History Enhances Working Memory Encoding: Evidence From Attribute Amnesia

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Accumulating evidence demonstrates that selection history influences the allocation of attention. However, it is unclear how working memory (WM), which is tightly connected to attention, is influenced by selection history. The aim of present study was to investigate the influence of encoding history on WM encoding. By incorporating task switching into an attribute amnesia task, participants' encoding history for stimulus attributes was manipulated and its corresponding influence on WM performance was tested. The results revealed that encoding an attribute in one situation can enhance the working memory encoding process for this same attribute in a different situation. Subsequent experiments revealed that this facilitation in WM encoding cannot be explained by increased attentional demand to the probed feature caused by the need to task switch. In addition, verbal instruction does not have a crucial influence on memory performance, which is mainly driven by prior experience in the task. Collectively, our findings lend unique insights into how selection history influences the encoding of information into WM.

Public Significance Statement

What information we encode into working memory determines what information we have access to when we decide how to act. The present study suggests that when deciding what information will be temporarily stored in memory under conditions with limited cognitive resources, our brains tend to prioritize contents that have been previously selected by our memory system, relying on past experience.

Keywords: selection history, working memory encoding, attribute amnesia, attention

Working memory allows people to hold and actively manipulate information that is related to current task goals over a short period of time (Baddeley, 1986). While working memory is important in human-environment interaction, its capacity is limited such that only about three to four pieces of information can be retained at any given moment in time (Cowan, 2001; Luck & Vogel, 1997; Vogel & Machizawa, 2004). With this limited capacity, selectivity becomes an important characteristic of working memory encoding processes.

The underlying processes and mechanisms that support the selectivity of working memory encoding have been subject to intense investigation. The most fertile and heavily explored branch of this research focuses on the relationship between attention and working memory. Accumulating evidence has shown that, to a large degree, information encoded and stored in working memory is influenced by selective attentional processes (e.g., Carrasco, 2006; Cowan et al., 2005; Kane & Engle, 2003; Martinez-Trujillo & Treue, 2004; Woodman & Vogel, 2008). For example, a number of studies had found that working memory performance and its relevant neural correlates are selectively enhanced for certain stimuli if these stimuli are cued by external cues or verbal instruction (Bocincova & Johnson, 2019; Janczyk & Reuss, 2016; Li & Saiki, 2015; Serences et al., 2009; Woodman & Vogel, 2008; Xu, 2010; Yu & Shim, 2017). Some researchers even argue that attention serves a gate-like function for working memory, determining what information can enter working memory storage (e.g., Gazzaley & Nobre, 2012; Lamme, 2004; Mack & Rock, 1998).

At the same time, a phenomenon referred to as *attribute amnesia* (Chen & Wyble, 2015) indicates that not all attended information enters working memory (a thorough description of the attribute amnesia paradigm will be provided later in this article). The phenomenon shows that if people did not expect to report a specific attribute (e.g., identity of a letter), they often fail to report it in a surprise test, even when they had just used and attended to that information for a visual search task (e.g., finding a letter among digits and reporting its location). Attribute amnesia had been repeatedly demonstrated and extended by many researchers (Born et al., 2019; Chen et al., 2016; Chen & Wyble, 2015, 2016; Chen, Yan, et al., 2019;

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Brian A. Anderson and Niya Yan jointly developed to the study concept and experiment design. James Grindell coded the experiment and supervised data collection. Niya Yan performed the data analyses with the assistance of James Grindell. Brian A. Anderson and Niya Yan interpreted the data. Niya Yan drafted the manuscript with input from Brian A. Anderson. All authors approved the final version of the manuscript for submission.

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Chen, Yu, et al., 2019; Harrison et al., 2021; Jiang et al., 2016; McCormick-Huhn et al., 2018; Swan et al., 2017), indicating that expectation also plays an important role in determining what information enters working memory storage.

Recently, the theoretical dichotomy of attention (top-down vs. bottom-up control) has been replaced by a trichotomy (biased by current goals, physical salience, and selection history; Anderson et al., 2021; Awh et al., 2012). This third new component of attentional control, selection history, has become a topic of substantial research interest. Within this framework, reward history, aversive conditioning, history as a sought target, statistical regularities among targets and nontargets, and other experience-dependent factors can shape the control of attention by facilitating the selection of some stimuli as well as facilitating the ignoring of others (e.g. Anderson et al., 2011, 2012; Della Libera & Chelazzi, 2009; Failing et al., 2019; Kim & Anderson, 2021; Liao et al., 2020; Nissens et al., 2017). For example, previously reward-associated (Anderson et al., 2011; Anderson & Yantis, 2013) and threat-associated stimuli (Anderson & Britton, 2020; Schmidt et al., 2015) can capture attention as task-irrelevant distractors.

Given the close relationship between attention and working memory, as well as their similarity in possessing the characteristic of information selectivity, a question arises concerning how working memory encoding processes might be influenced by prior experience. More specifically, does selection history with respect to working memory encoding bias future working memory encoding? Answering this question is important because it not only helps us better understand the mechanism of working memory encoding, it can also deepen our knowledge on the interaction between attention, working memory, and prior experience. There have been a few studies showing that reward history can enhance working memory performance (Gong & Li, 2014; Infanti et al., 2015; Thomas et al., 2016; Wallis et al., 2015). Kuo (2016) also found that people's working memory capacity can be influenced by their prior experience. However, research exploring the role of selection history in working memory encoding is still in a nascent stage and mostly focused on reward history specifically. The present study explores how encoding history in a visual working memory (VWM) task influences working memory encoding. Considering the influence of expectation on working memory encoding, as well as the difficulty in teasing it apart from attention in traditional working memory tasks, a variation of the attribute amnesia paradigm was used in this study, so that the relationship between working memory encoding and encoding history can be observed in conditions where expectation is effectively controlled.

In a typical attribute amnesia task (see Figure 1), participants are presented with three colored digits and one colored letter and are asked to report the location of the letter in a series of trials. Then, on a surprise trial, participants are unexpectedly asked to report the identity and color of the letter. As mentioned earlier in this paper, most participants fail to complete the surprise test accurately, even though they had attended to the identity information in order to locate the target letter. Trials immediately following the surprise trial that are identical in procedure are referred to as control trials, performance on which is typically significantly better than it is for the surprise trial. This significant difference between control trials and surprise trials is referred to as the attribute amnesia effect (Chen & Wyble, 2015).

By incorporating task switching into the attribute amnesia task, Experiment 1 of the present study manipulates participants' encoding history for stimulus identity and tests its corresponding influence on VWM performance for identity information. In presurprise trials, while participants in the variable probe group switch between reporting the color of a target digit among distractor letters and reporting the identity of a target letter among distractor digits, participants in the consistent probe group only reported the color of the target regardless of whether it was a letter or digit. Then participants in both groups were unexpectedly asked to report the identity of a target digit in a surprise trial. Although no participant had ever been asked to report the identity of a digit, participants in the variable probe group had experience reporting the identity of letters. Of interest was whether the experience of being probed on the identity of letters would result in participants being more likely to encode the identity of any stimulus including digits, or whether the effects of encoding history on future stimulus encoding would be stimulus-specific.

Experiment 1

Method

Participants

Of the participants, 240 participants ($M = 18.846$ years of age, $SD = 1.013$, 164 female) were recruited from the Texas A&M University community. We performed a power analysis using G*Power 3.1 (Faul et al., 2007). The attribute amnesia effect size (φ) was estimated as 0.40 according to Chen, Yan, et al. (2019). The power calculation yielded a power of 0.99 (with α set to 0.05) using the obtained sample size. Participants were randomly assigned into two groups: 120 to the variable probe group and 120 to the consistent probe group. All participants reported normal or corrected to normal visual acuity and normal color vision. Participants were compensated with course credit. All procedures were approved by the Texas A&M University Institutional Review Board and conformed with the principles outlined in the Declaration of Helsinki.

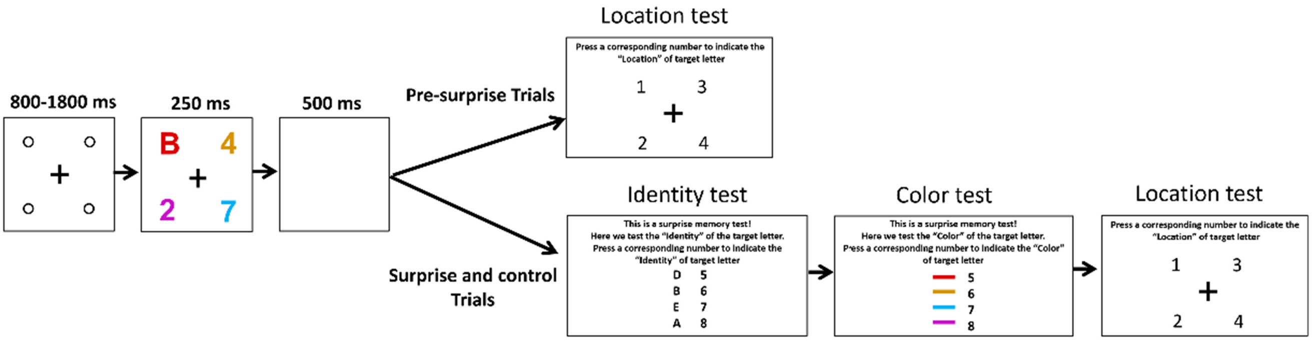
Apparatus

A Dell OptiPlex 7040 equipped with jsPsych (De Leeuw, 2015) was used to generate and host the experiment using the JATOS framework (Lange et al., 2015), as previously described (Liao et al., 2021). Each participant used their own device to complete the experiment in a web browser.

Stimuli

At the beginning of each trial, a word cue was presented at the center of the screen to indicate participants target category for the trial. Then, a white fixation cross (80 × 80 pixels) was centered among four white placeholder circles (80 × 80 pixels) presented on the four corners of an invisible square. The stimulus array contained either one English letter target (A, B, D, E, G, H, K or M; 80 × 80 pixels) and three Arabic numeral distractors (2–9; 80 × 80 pixels) or one Arabic numeral target (2–9; 80 × 80 pixels) and three English letter distractors (A, B, D, E, G, H, K or M; 80 × 80 pixels). The letters and the digits were presented at the same locations as the four placeholders. Each stimulus was randomly assigned one of four colors, red (RGB: 200, 0, 0), green (RGB: 0, 190, 0), yellow (200, 200, 0), or blue (0, 80, 255), with no repetition of color in one array. All stimuli were presented on a black background.

Figure 1
Procedure of the Classic Attribute Amnesia Task (Chen & Wyble, 2015)



Note. See the online article for the color version of this figure.

Procedure and Design

This experiment incorporated task switching and variable target category into the classic attribute amnesia task as depicted in Figure 1. All participants switched between searching for a target letter, where one attribute of the only letter was probed, and searching for a target digit, where one attribute of the only digit was probed (see Figure 2a). For participants in the variable probe group (see Figure 2b), in 127 pre-surprise trials, participants switch between reporting the identity of a target letter and reporting the color of a target digit. That is, the task they performed switches with the target category they are searching for. Target category and the corresponding report task alternated every two trials. Each trial started with a 1,000-ms word cue indicating the target category for the trial ("Digit" presented at the center of the screen for a digit task; "Letter" presented at the center of the screen for a letter task). After that, the fixation display was presented for a duration that varied randomly between 800 and 1,800 ms. Then, the stimulus display appeared for 250 ms, which consisted of three colored digits and one colored letter (letter task) or three colored letters and one colored digit (digit task). The stimulus display was followed by a 500 ms blank screen.

For the digit task, participants were presented with a forced-choice question asking them to indicate which of four colored lines matched the color of the target digit, while for the letter task, participants were presented with a forced-choice question asking them to indicate which of four black letters was the (target) letter that they had just seen on that trial. The 128th trial was the surprise trial in which before the color test, participants were presented with a four-alternative forced-choice question which unexpectedly asked them to indicate which of four black digits was the (target) digit that they had just seen on that trial. After the surprise trial, participants received three control trials (Trials 129–131), in which they were always asked to indicate the identity then the color of a target digit among three letters. As in the original attribute amnesia paradigm (e.g., Chen & Wyble, 2015), for all response displays in our experiments, participants pressed the number keys (1, 2, 3, or 4) to indicate their choice from the four response options provided, where the locations of the numbers in the response display were fixed and the mappings between the response options and number keys were randomized on each trial (e.g., the response option mapped to the "1" key was always presented at the top of the response display while the response option that it was mapped to varied across trials). In this way, the manner in which participants selected and entered a response on surprise trials was designed to require as little task reconfiguration as possible.

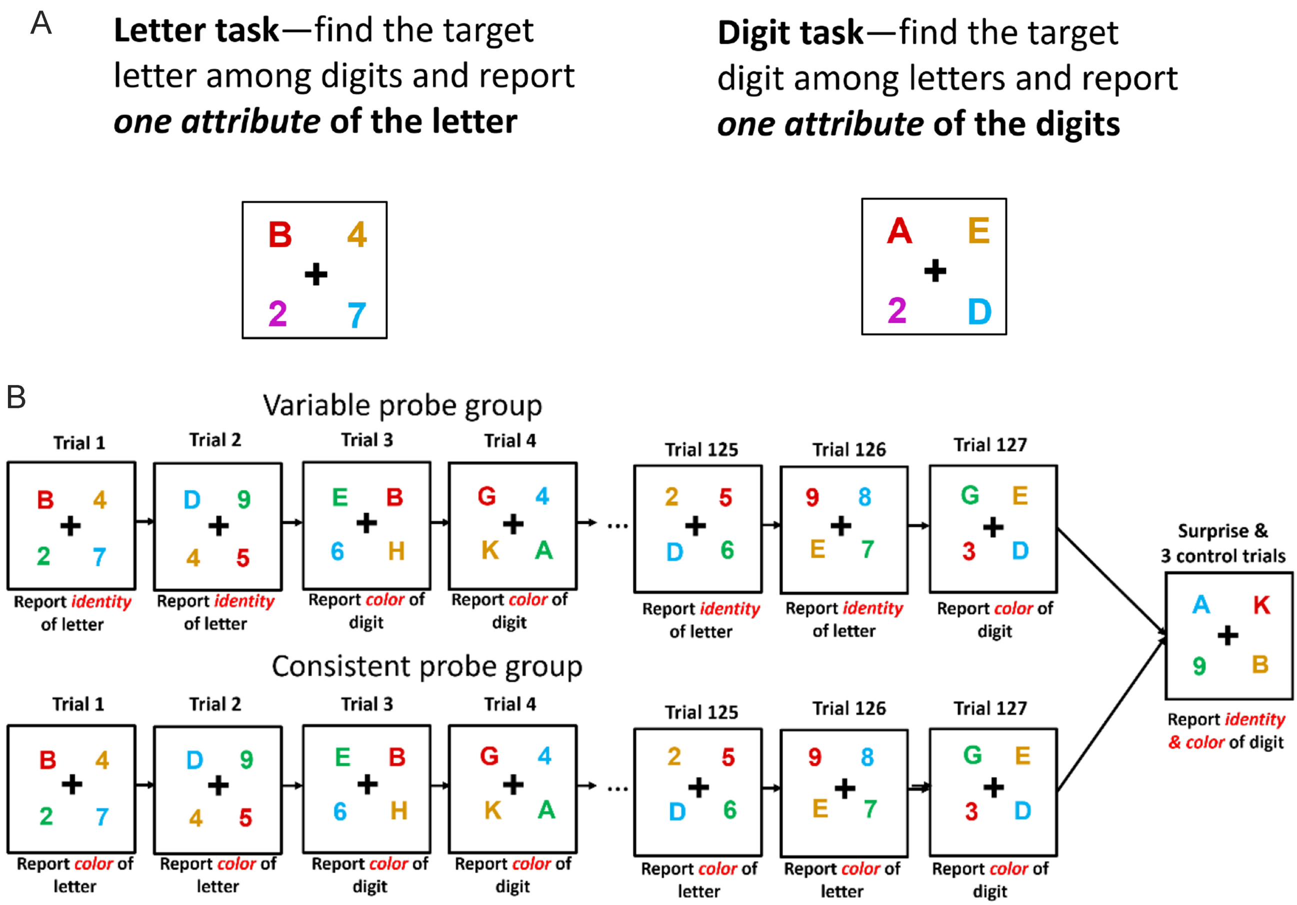
In addition to response accuracy, we also recorded response time (RT) from the onset of the probe array. For participants in the consistent probe group (see Figure 2b), the procedure was identical to that for the variable probe group except that in the 127 pre-surprise trials, regardless of whether it was the letter task or the digit task, participants were asked to report the color of the target. To maintain consistency of instruction across participant group, all participants were informed that either the color or identity of the target could be probed.

Results

Accuracy

The results of Experiment 1 are shown in Table 1 and Figure 3. The reporting accuracy on the pre-surprise trials for the variable probe group were 81% for the digit task (color probed) and 89% for the letter task (identity probed). The reporting accuracy on the pre-surprise trials for the consistent probe group was 85% for digit task (color probed) and 87% for letter task (color probed). All these indicate that participants could accurately locate the target among distractors and report a probed feature of the target. A McNemar's test was used to compare participants' identity reporting accuracy between the surprise trial and the first control trial, since this test is the most appropriate one for analyzing paired dichotomous data (Adedokun & Burgess, 2012). We found a significant attribute amnesia effect in the consistent probe group but found no significant attribute amnesia effect in the variable probe group. For the consistent probe group, participants exhibited a dramatic increase in reporting accuracy of the target digit identity from the surprise trial (69%) to the first control trial (88%), $\chi^2(1, N = 120) = 15.11$, $p < .001$, $\varphi = 0.35$. For the variable probe group, reporting accuracy of the target digit on the surprise trial (86%) was similar to that on the first control trial (85%), $\chi^2(1, N = 120) = 0.04$, $p = .83$, $\varphi = 0.019$. These results show that the attribute amnesia effect was replicated in the consistent probe group but not observed in the variable probe group. Critically, a traditional chi-square test was used for between group comparison of reporting accuracy of target identity on the surprise trials, which showed that surprise test memory performance of target identity in the variable

Figure 2
(a) Stimulus Display for Letter Task and Digit Task, (b) Design of Experiment 1



Note. See the online article for the color version of this figure.

probe group was significantly better than that in consistent probe group, $\chi^2(1, N = 240) = 9.56$, $p = .002$, $\varphi = 0.20$.

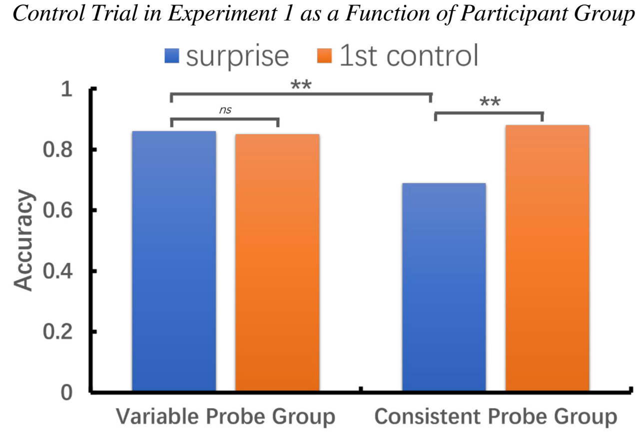
Participants in both groups exhibited a significant decline in the accuracy of reporting the target color in the surprise trial (variable probe group: 53%; consistent probe group: 61%) compared with that in the pre-surprise (variable probe group: 82%; consistent probe group: 85%), $ps < .001$ (based on comparisons between the surprise trial and the last pre-surprise trial in each group) and control trials (variable probe group: 65%, 82%, 85%; consistent probe group: 76%, 85%, 84%), $ps < .006$, with the exception of the comparison between the surprise and the first control trial in the variable probe

Table 1
Accuracy Results of Experiment 1 (N = 120 in Each Group)

Task		Pre-surprise	Surprise	Contr.1	Contr.2	Contr.3
Variable probe group						
Digit task	Color	0.82	0.53^2	0.65	0.82	0.85
	Identity	N/A	0.86^1	0.85	0.90	0.89
Letter task	Color	N/A	N/A	N/A	N/A	N/A
	Identity	0.89	N/A	N/A	N/A	N/A
Consistent probe group						
Digit task	Color	0.85	0.61^2	0.76	0.85	0.84
	Identity	N/A	0.69^1	0.88	0.88	0.93
Letter task	Color	87%	N/A	N/A	N/A	N/A
	Identity	N/A	N/A	N/A	N/A	N/A

Note. Superscripts indicate the order in which questions were asked in the surprise and following control trials. N/A = Not available.

Figure 3
Reporting Accuracy of Identity in the Surprise Trial and the 1st Control Trial in Experiment 1 as a Function of Participant Group



Note. ns = not significant. See the online article for the color version of this figure.
$^*p < .05$. $^{**}p < .01$.

group, $p = .059$. A similar pattern of performance decrement on the surprise trial for a previously probed attribute is commonly observed in attribute amnesia studies (Chen & Wyble, 2015, 2016; Chen, Yan, et al., 2019; Chen, Yu, et al., 2019; Harrison et al., 2021; McCormick-Huhn et al., 2018; Swan et al., 2017) and may reflect the fact that the test question for this task-relevant attribute (e.g., color test question in the present study) was presented immediately after the surprise test question (e.g., identity test question in the present study), causing some participants to forget the task-relevant attribute while answering the surprise question (Chen & Wyble, 2016).

RT

For pre-surprise trials, only correct responses were included, the first trial of every participant was removed, and then RTs faster than 200 ms and slower than 2.5 standard deviations from the mean (computed separately for each participant) were trimmed, collectively resulting in 17.66% of responses being removed for the variable probe group and 17.42% of responses for the consistent probe group. There was one outlier in the variable probe group whose mean RT was 7,907 ms (>3*SD* from the group mean), and this participant's RT data were excluded from analysis.

An independent samples *t*-test was used to compare the pre-surprise trial RT between the variable probe group and the consistent probe group. Participants responded significantly faster in the consistent probe group ($M = 1{,}211.78$ ms, $SD = 302.10$) compared to the variable probe group ($M = 1{,}417.59$ ms, $SD = 305.98$), $t(237) = -5.23$, $p < .001$, $d = 0.68$.

Next, RTs for the identity probe on the surprise trial were compared between the different groups, where responses in the consistent probe group ($Mdn = 4{,}600$ ms) were slower than that in the variable probe group ($Mdn = 1{,}898.1$ ms). Since the normality assumption was violated, a Mann–Whitney test was performed in place of a *t*-test, which indicated that this difference was statistically significant, U $(N_{\text{consistent probe}} = 120,\ N_{\text{variable probe}} = 120,) = 2{,}784$, $z = -8.21$, $p < .001$. RTs for the identity test on the first control trial were also compared between the two groups, where responses in the consistent probe group ($Mdn = 2{,}179.7$ ms) were again significantly slower than that in the variable probe group ($Mdn = 1{,}825.8$ ms), $U(N_{\text{consistent probe}} = 120,$ $N_{\text{variable probe}} = 120,) = 5{,}603$, $z = -2.97$, $p = .003$.

Discussion

Our results indicate that the encoding history of one attribute of target items dramatically improves participants' performance in a surprise test probing the same attribute of a categorically different target item. While the attribute amnesia effect was replicated in the consistent probe group, no attribute amnesia effect was observed in the variable probe group. More importantly, surprise trial memory performance for identity was significantly better in the variable probe group compared to that in the consistent probe group. These results indicate that encoding history has a facilitating influence on VWM encoding that is not stimulus-specific: a history of being probed on the identity of a target resulted in participants being more likely to encode target identity regardless of the category of stimulus encoded into memory and whether the identity of that particular category of stimulus had ever been probed before.

Results concerning RT suggest that the need to switch between reporting task is attentionally demanding, resulting in slower responses compared to participants who experienced the same task demands with respect to target identification but did not need to switch between reported features. It was also the case that participants in the variable probe group responded more quickly to the surprise test, potentially because they were more confident in their answer and/or were more familiar with questions probing identity in general, allowing them to more quickly discern what was being asked of them. At the same time, the variable probe groups' quicker responses in the surprise and first control trials also indicated that there is no evidence for a speed-accuracy tradeoff in the results.

Considering the fact that participants in the consistent probe group did not have prior experience reporting the identity of any category of target before the surprise trial, it might be argued that digit identity was remembered equally well for participants in both groups while the added novelty of the surprise trial in the consistent probe group resulted in a larger task reconfiguration cost that led to less efficient information extraction and less accurate reporting performance, which provides an alternative explanation for the differences observed between these two groups. We cannot exclude this possibility completely, since a cost of switching to a novel reporting task has been observed in some attribute amnesia studies. For instance, Wyble and his colleagues observed a large response time difference between the first and second surprise question on the surprise trial (Wyble et al., 2019). Also, Swan et al. (2017) unexpectedly altered reporting requirements from target identity recognition to target identity recall halfway through the experiment and observed a slight decrease in participants' identity reporting accuracy on the surprise trial (75% correct) compared to the pre-surprise trial (91% correct).

There are, however, several factors suggesting that an effect of prior experience on the novelty of the surprise test is unlikely to provide a complete account of our data. For example, still in Swan et al. (2017), no significant difference was observed between the surprise trial reporting accuracy (75% correct) and the first control trial reporting accuracy (85%), showing no attribute amnesia effect. The findings of Swan et al. (2017) suggest that even though there is some cost of a surprise probe, the presence or absence of the attribute amnesia effect is not solely attributable to surprise. In this context, it is also worth noting that our surprise trial would be expected to have been comparatively less surprising for participants in both groups, since the reporting requirement (layout of response options and mapping to response keys) was consistent across all trials (rather than switching from recognition to recall as in Swan et al., 2017). Further, in Chen, Yan, et al. (2019), a second surprise trial was added to the classic attribute amnesia task (e.g., probed target color in the first surprise trial, then probed target identity in the immediately following second surprise trial) and reduced reporting accuracy was only observed in the first surprise trial, suggesting that the cost of deciphering a novel probe per se is not sufficient to lead to poor memory performance. Therefore, although different degrees of surprise concerning the critical surprise probe between participant groups may have to some degree influenced performance in our task, we think it is unlikely that participants in both groups encoded identity information equally well and that our findings would be solely attributable to forgetting during the process of responding to the probe.

Experiment 2

In Experiment 1, for both groups of participants, the target category was variable, requiring that participants consistently monitor and maintain in active memory what the current target category is. This differs from traditional attribute amnesia experiments in which the target category remains constant (e.g., Chen & Wyble, 2015). Experiment 2 examines whether and how this increased memory demand influences the encoding of information in VWM. On the one hand, consistently needing to distinguish the current target category might interfere with the encoding of target identity in general, with participants experiencing greater interference from nontargets and thus encoding the target features less robustly, especially features that are not reliably probed. On the other hand, the demand to monitor target category might facilitate greater attention to the identity of the target even when its identity has never been probed and/or the repetition of a consistent target category might facilitate more automatic and shallow encoding of the target, resulting in improved memory in the face of variable target category. Experiment 2 adjudicates between these possibilities by comparing performance between the consistent probe condition of Experiment 1 with that for a group of participants for whom the target category remains consistent over trials.

Method

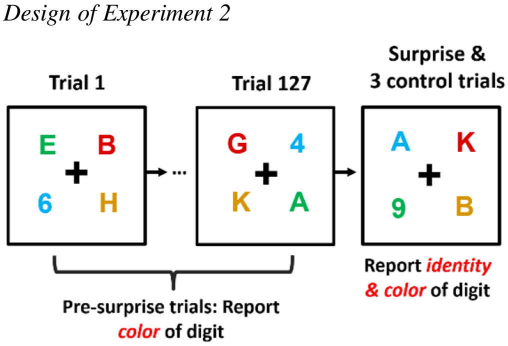
This experiment was identical to the consistent probe group in Experiment 1 except that the target was only ever a digit (see Figure 4) and thus no word cue was presented for each trial. A different 120 Texas A&M University students ($M = 19.29$ years of age, $SD = 1.064$, 60 female) completed Experiment 2 for course credits.

Results

RT

For pre-surprise trials, using the same trimming rules in Experiment 1, 10.44% of responses were removed for the consistent target category group (Experiment 2). Mean RT in the consistent target category group ($M = 1{,}047.59$. $SD = 272.94$) was significantly faster than that in the consistent probe group in Experiment 1 ($M = 1{,}211.78$ ms, $SD = 302.10$), $t(238) = -4.412$, $p < .001$, $d = 0.57$. For the identity test in the surprise trial, responses in the consistent probe group ($Mdn = 4{,}600$) were numerically slower from those in the consistent target category group ($Mdn = 4{,}233.4$), although the difference between these two groups was not significant, $U(N_{\text{consistent probe}} = 120,\ N_{\text{consistent target category}} = 120,) = 6{,}606.00$, $z = -1.11$, $p = .269$. For the identity test in the first control trial, responses in the consistent probe group ($Mdn = 2{,}179.7$) again did not differ significantly from those in the consistent target category group ($Mdn = 1{,}943.2$), $U(N_{\text{consistent probe}} = 120,\ N_{\text{consistent target category}} = 120,) = 6{,}276.00$, $z = -1.72$, $p = .086$.

Figure 4
Design of Experiment 2



Note. See the online article for the color version of this figure.

Accuracy

As shown in Table 2 and Figure 5, the results of this experiment were similar to those for the consistent probe group in Experiment 1. The attribute amnesia effect was replicated, as the reporting accuracy of identity in the surprise trial (80%) was significantly worse than that in the first control trial (91%), $\chi^2(1, N = 120) = 8.05$, $p = .005$, $\varphi = 0.26$. Comparing surprise test performance between the consistent target category group of Experiment 2 (80%) and the consistent probe group in Experiment 1 (69%), no significant difference was observed, $\chi^2(1, N = 240) = 3.71$, $p = .054$, $\varphi = 0.12$, with the trend being in the direction of improved performance in the consistent target category group[1]. As in Experiment 1, participants' performance of color report on the surprise trial (50% correct) was worse than the pre-surprise trials (93% correct) and control trials (85%, 88%, and 85% correct), $ps < .001$.

Discussion

The results of Experiment 2 revealed that, without the demand of needing to monitor the current target category, the attribute amnesia effect can still be observed and participants' performance on a surprise trial was not impaired relative to participants for whom the target category repeatedly switched. There was a trend toward improved performance with a consistent target category, although the difference was not significant. Our data provide convincing evidence against the idea that the repetition of a consistent target category facilitates more shallow encoding of the target, which might be expected to result from more automatic selection processes. In this respect, our data argue against the idea that the classical attribute amnesia effect is the product of target selection that is somewhat automated due to repetitive selection demands. The RT results from Experiment 2 are consistent with our assumptions concerning attentional demand, with a consistent target category producing substantially faster RT on pre-surprise trials. Our findings from Experiment 2 also rule out the possibility that increased attentional demand could explain the results of Experiment 1, since in Experiment 2 the participant group with the least attentional demands (neither target category nor probed feature switch over trials, resulting in the fastest RT in probe report) exhibited numerically higher, albeit not significantly different, reporting accuracy on the surprise trial compared to the participant group with medium attentional demand (only target category switches over trials, resulting in a slower RT in probe report). RT data for the critical and control trials in Experiment 2 were again inconsistent with a speed-accuracy tradeoff.

[1] The data were also examined by estimating a Bayes factor using Bayesian information criteria Wagenmakers, 2007), comparing the fit of the data under the null hypothesis and the alternative hypothesis (computed using JASP 0.14.1.0 with default priors). An estimated Bayes factor (null/ alternative) suggested that the data were 1.13:1 in favor of the null hypothesis.

Table 2
Accuracy Results of Experiment 2 (N = 120)

Attribute	Pre-surprise	Surprise	Contr.1	Contr.2	Contr.3
Consistent target category group					
Color	0.93	0.50^2	0.85	0.88	0.85
Identity	N/A	0.80^1	0.91	0.94	0.92

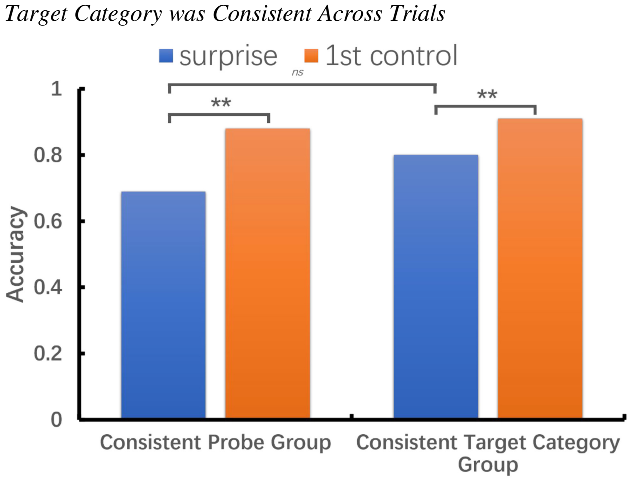
Note. Superscripts indicate the order in which questions were asked in the surprise and following control trials. N/A = Not available.

Experiment 3

Experiment 2 demonstrates that having a consistent target that is repeatedly selected over trials does not exaggerate the attribute amnesia effect, which would have been expected if attribute amnesia is the product of more automated selection, and selective encoding, of targets. If anything, the trend was in the opposite direction, with greater attentional demand associated with a variable target category resulting in a numerically larger attribute amnesia effect. Our results here also rule out an account of the findings of Experiment 1 in which the reduced attribute amnesia effect in the variable probe group is reduceable to the increased attentional demand and slower responding associated with the need to switch between reported feature.

In all experimental conditions so far, in an effort to maintain consistency of instruction across conditions, participants were informed of the possibility of either target color or identity being probed. In both Experiment 2 and the consistent probe condition of Experiment 1, although participants were probed on target identity for the first time on the surprise trial, they were not naïve about the possibility of such a probe occurring. This contrasts with the traditional attribute amnesia task, in which task instruction makes no explicit reference to identity as a probed feature (Chen & Wyble, 2015). An interesting question arises concerning the role of task instruction per se in attribute amnesia. To what degree does explicitly informing participants about the possibility of target identity being probed facilitate the encoding of target identity after many trials of target identity not being probed? Experiment 3 addresses this question by replicating Experiment 2 but removing reference to target identity as a potentially probed feature during task instruction.

Figure 5
Reporting Accuracy of Identity in the Surprise Trial and the 1st Control Trial, Comparing Participants in the Consistent Probe Group of Experiment 1, for Whom the Target Category Switched Across Trials, and Participants in Experiment, 2 for Whom the Target Category was Consistent Across Trials



Note. *ns* = not significant. See the online article for the color version of this figure.
*$p < .05$. **$p < .01$.

Method

This experiment was identical to Experiment 2 except that there is no mention of identity as a probed feature in the task instruction. Participants were instructed only to report target color. A different 120 Texas A&M University students ($M = 19.317$ years of age, $SD = 1.901$, 69 female, 49 male [2 no response]) completed Experiment 3 for course credits.

Results

Accuracy

The results of Experiment 3 are depicted in Table 3 and Figure 6. The accuracy on the pre-surprise trial was 93%, which indicates that participants could accurately locate and report the color of the target digit. Participants' identity report performance on the first control trial (93%) was significantly better than that in the surprise trial (73%), $\chi^2(1, N = 120) = 18.00$, $p < .001$, $\varphi = 0.39$, replicating the attribute amnesia effect. Interestingly, no significant difference in surprise test identity reporting accuracy was observed between current experiment and Experiment 2 (80%), $\chi^2(1, N = 240) = 1.86$, $p = .172$, $\varphi = .09$. And similar to the previous experiments, participants' performance of color report was worse in the surprise trial (61% correct) compared with the pre-surprise (93% correct) and control trials (85%, 93%, and 93% correct), $ps < .001$.

RT

For the classic attribute amnesia group, 9.65% of responses in the pre-surprise trails were removed (Experiment 3). There was one outlier whose mean RT was 9,644 ms (>3*SD* from the group mean), and this participant's RT data were excluded from analysis. Mean RT in the classic attribute amnesia group ($M = 1{,}048.19$. $SD = 271.08$) was not significantly different from that in the consistent target category group ($M = 1{,}047.59$. $SD = 272.94$), $t(237) = 0.017$, $p = .986$, $d < 0.01$. No significant differences in identity test RTs were observed between the two groups for both the surprise (consistent target category group $Mdn = 4{,}233.4$, classic AA group $Mdn = 4{,}534.2$), $U(N_{\text{consistent target category}} = 120, N_{\text{classic AA}} = 120,) = 6{,}169.00$, $z = -1.91$, $p = .055$, and the first control trial (consistent

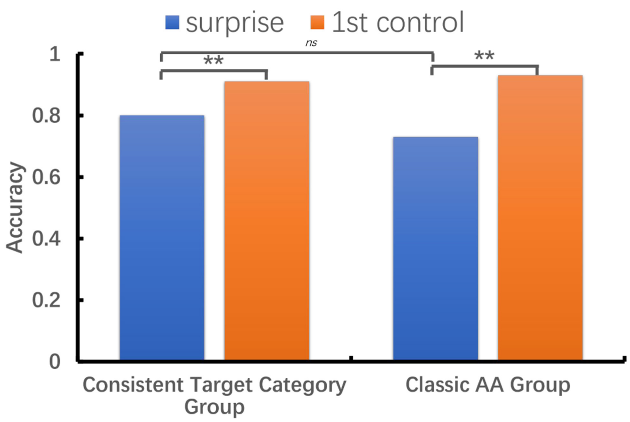
Table 3
Accuracy Results of Experiment 3 (N = 120)

Attribute	Pre-surprise	Surprise	Contr.1	Contr.2	Contr.3
Classic attribute amnesia group					
Color	0.93	0.61^2	0.85	0.93	0.93
Identity	N/A	0.73^1	0.93	0.93	0.93

Note. Superscripts indicate the order in which questions were asked in the surprise and following control trials. N/A = Not available.

Figure 6

Reporting Accuracy of Identity in the Surprise Trial and the 1st Control Trial in Experiment 2 and Experiment 3



Note. *ns* = not significant. See the online article for the color version of this figure.
$^{*}p < .05$. $^{**}p < .01$.

target category group $Mdn = 1{,}943.2$, classic AA group $Mdn = 2{,}106.0$), $U(N_{\text{consistent target category}} = 120, N_{\text{classic AA}} = 120,) = 6{,}658.50$, $z = -1.01$, $p = .314$.

Discussion

The results of Experiment 3 revealed that whether identity is mentioned as a probed attribute in task instruction makes little difference in participants' reporting accuracy for target identity in the surprise test. Although accuracy was numerically higher when target identity was mentioned as a possible probed feature in task instruction (Experiment 2), this difference was not significant in spite of a sample size of $N = 120$ in each group of participants. Thus, it appears that experiential history rather than task instruction plays the more dominant role in what information is encoded into VWM. The RT results from Experiment 3 are further consistent with the idea that the difference in task instruction between groups was not consequential for memory probe performance.

General Discussion

In the present study, we investigated the influence of selection history on working memory encoding across three experiments. Experiment 1 showed that with the prior experience of reporting the identity of one type of target, most participants were able to report the identity of the categorically different target in a later surprise test, indicating a facilitating role of encoding history on VWM encoding. Experiment 2 ruled out the possibility that the observed memory improvement tied to encoding history in Experiment 1 could be explained by increased attentional demand. We do not see evidence that consistently encoding the same target attribute across trials potentiates attribute amnesia, or by extension that needing to flexibly update task-related search goals facilitates encoding of historically unprobed target features. Experiment 3 further validated that experiential history, rather than task instruction, plays the more dominant role in deciding information encoded into VWM.

While influential views have posited that goal-consistent and physically salient stimuli are more likely to capture attention (Carrasco, 2006; Corbetta & Shulman, 2002; Folk et al., 1992; Itti & Koch, 2001; Wolfe et al., 1989), and thus have a higher probability of entering working memory storage (Cowan et al., 2005; Gazzaley & Nobre, 2012; Kane & Engle, 2003; Lamme, 2004), little attention has been paid to how other factors influence working memory storage. The findings from the current study provide evidence that speaks to how learning influences working memory encoding. More specifically, results from Experiment 1 show that, even when there is no need to do so, features that have been previously encoded into working memory can be better represented in working memory and survive a surprise memory question. Findings from Experiments 2 and 3 show that without a history of encoding certain attributes, even when being explicitly informed about the possibility of these attributes being probed, people tend not to store that information in their working memory. These three experiments collectively indicate that information represented in working memory is influenced by learning from prior experience.

Our findings are broadly consistent with studies examining the influence of reward learning on working memory performance, which show that working memory representations can be biased by reward history (e.g., Gong & Li, 2014; Infanti et al., 2015; Thomas et al., 2016; Wallis et al., 2015). The present study is unique in showing that besides reward history, encoding history can also boost the probability that certain stimulus attributes will enter working memory storage. Also, unlike previous reward learning studies, which test participants' working memory when they are fully prepared for the working memory test, the present study probes working memory representations with a surprise question, removing the influence of peoples' intention in working memory encoding.

Our findings also speak to the specificity of the filters for encoding. The fact that consistently reporting the identity of one category of stimulus (letters) enables the encoding and reporting of the identity of a different category of stimuli (digits) suggests that identity encoding may to some degree reflect a generalized mode of information processing. That is, participants seem to more so learn how they should encode task-relevant stimuli than how to encode particular categories of objects in a stimulus-specific manner. At the same time, the findings of the present study can extend our understanding of how attended objects are represented in memory. Slightly different from findings of classic attribute amnesia studies, which challenged the object-based encoding theory and showed that people are more likely to encode task-relevant features and filter out remaining irrelevant features of an attended object (feature-based encoding, e.g., Serences et al., 2009; Woodman & Vogel, 2008), our findings suggested that feature encoding history from one category of object can increase the scope of the encoding filter to enable the same feature from another category of object to be represented in working memory. On top of stimulus-specific encoding, there may exist a domain-general filter that is applied generally within the context of a particular task situation. Future research might seek to further explore the scope of the attentional filters that develop as a result of selection history.

Participants' pre-surprise trial performance in Experiment 1 (variable probe group: 82% correct for digit color, 89% correct for letter identity; consistent probe group: 85% correct for digit color, 87% correct for letter color) is slightly lower than that in Experiment 2 (93% correct), Experiment 3 (93% correct), and other attribute amnesia studies where reporting accuracy in pre-surprise trials is usually higher than 90% (e.g., Chen et al., 2016; Chen & Wyble, 2015, 2016). This departure from the average pre-surprise trial performance suggests that the task-switching requirement of Experiment 1 to some degree impedes target encoding more generally. Under these conditions, participants have to first identify which type of target they are searching for before encoding its attributes, which may serve to increase competition from nontarget attributes that may in turn be less efficiently filtered.

The results from our study can be compared with Chen, Yan, et al. (2019), which adopted a variation of the AA task paradigm to examine the influence of expectation violation on information processing. In that study, participants were asked to report the location of the target letter in pre-surprise trials and were then unexpectedly asked to report a different attribute (color or identity) of the target letter in the first surprise trial, then were asked to report another unexpected attribute of the target letter (identity or color, respectively) in an immediately following second surprise trial. Similar to the present study, a reduced attribute amnesia effect was observed in the second surprise trial in their experiment, which indicates a switch from a highly selective and exploitive information processing strategy to a more flexible and explorative information processing strategy after expectation violation. The primary manipulation in the present study is similar to that study in that both studies involve task switching between reporting identity and reporting color. The difference is that, in our study, task switching was used in pre-surprise trials to establish encoding history for a certain attribute, while in Chen, Yan, et al. (2019) study, task switching was used in surprise trials to test the immediate consequences of a violation of expectation. Also, Chen, Yan, et al. (2019) study indicates that working memory encoding can be generalized to different attributes on the same target, while results from the present study showed that encoding history for an attribute is not restricted to only one kind of target, but can also transfer to a categorically different target. At the same time, both studies are consistent in showing that learning can influence working memory encoding. The significant difference in the attribute amnesia effect between the two groups in our Experiment 1 extend the findings from Chen, Yan, et al. (2019) by indicating that besides expectation violation, selection history may also facilitate a transfer from a highly selective and exploitative information processing strategy to a comparatively more flexible and explorative information processing strategy.

The results from our study can also be compared with a recent study by Zivony and Eimer (2022), which also involved a switch in target category. They presented target stimuli in rapid serial visual presentation (RSVP) streams and unexpectedly altered the category of the focally attended target from a repeated category (e.g., letter) to a different category (digit) in the critical trial. What they found was a decrement in identity reporting accuracy for the target on the critical trial, indicating that the focally attended information failed to be noticed and reported when unexpected. At first glance, their results seem to be in conflict with ours, since their participants showed a failure in reporting the same attribute when target category unexpectedly changed from letter to digit, while participants in our variable probe group were able to report the same attribute when it was probed on an unexpected target category. However, one likely important difference is that an RSVP task is designed to examine attentional *selection* whereas the attribute amnesia task is used to examine how information that is attended enters into working memory storage. Therefore, our findings complement Zivony and Eimer (2022) in showing that selection history can enhance working memory encoding for an attended object, at the same time shaping which information is selectively attended (see Anderson et al., 2021).

The present study probed memory for stimulus identity, the processing of which was required to distinguish between the target and distractors. In the literature on attribute amnesia, identity is typically regarded as a key feature (Chen & Wyble, 2015, 2016), which refers to the target-defining feature that participants are not required to report but need to attend to and use to perform the task (Botella et al., 2001; Remington & Folk, 2001). We did not examine the influence of encoding history on color, or any other attribute that was peripheral to the information required to identify the target. Future studies could examine the influence of encoding history across a broader range of features, including features that are unrelated to the task of identifying the target, which would help to establish the scope with which selection history influences working memory encoding. Another limitation of the present study, and the attribute amnesia paradigm more broadly, reflects the reliance on a single key surprise trial. This approach requires a large sample size, restricts conclusions to an all-or-none measure of report accuracy, and reveals very limited insight into the time course of learning-dependent influences. Future studies can try to replicate and extend the present study's conclusions using other paradigms that can probe unintentional working memory processing without the reliance on a surprise question.

With the conclusion that working memory encoding can be facilitated by selection history, the findings from the present study cannot tell us whether the strengthened memory traces we observed are caused by selection history directly or through other mediating factors, such as attention. Future studies can probe the involvement of attention in this process by further manipulating the attentional demands of the task or monitoring electroencephalographic signals that are associated with attention (e.g., N2pc, a component that is thought to reflect the allocation of attention to items in the search display, see Eimer, 1996; Hickey et al., 2009) when participants are performing the task.

Using the attribute amnesia paradigm, our study explores how encoding history influences working memory encoding. We found that stimulus attributes with a history of entering working memory can be prioritized in working memory encoding, thus reducing the attribute amnesia effect. Consistently searching for the same target stimulus does not result in a reduced likelihood of encoding attributes of the target that have not been historically probed, as might have been expected from more automated and shallow encoding built up through repetition, and mere knowledge that a feature could be probed in the task does little to the likelihood that this feature will be reported when probed. These finding have implications for working memory theories, learning theories, and the selection history literature. The results from the present study provide evidence that, in addition to goal-consistency and physical salience, experiential history jointly determines what information enters working memory storage, providing a richer perspective on working memory processes. Many studies have demonstrated that individual differences in working memory performance are important for understanding differences in people's learning capability (Cowan, 2014), but far fewer studies investigate how learning influences working memory processes. Results from current study support the idea that the relationship between learning and working memory is bidirectional, particularly as it pertains to the contents of working memory. Although there is now a wealth of evidence speaking to the close relationship between working memory and attention, as well as the interaction between attention and selection history, comparatively little is known about the relationship between working memory and selection history. The findings from the present study both highlight an integral role for selection history in understanding what information gets encoded into working memory and provide an experimental framework for further investigation of the relationship between VWM encoding and selection history.

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