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Are Selection History Effects Limited to Implicit Forms of Memory? Evidence from Inter-trial Repetition

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Abstract

Selection history effects in visual attention are typically considered implicit memory effects. In three experiments, we investigated if a key selection history effect, inter-trial priming, could be based on the incidental application of explicit memory. In the basic search task (Experiment 1), participants searched for real-world objects from different categories. We examined non-predictive, inter-trial repetition at two levels: 1) the repetition of target location from trial N-1 to trial N, and 2) the repetition of target location and color within a category. Reliable repetition advantages were observed at both levels. In Experiments 2-4, we examined whether participants had explicit access to the target values driving the selection history effects here. In Experiment 2 and 3, participants could reliably report the properties of the immediately preceding search target. In Experiment 4, participants could reliably report the properties of the last target exemplar they had found in each of the 36 categories. These data indicate that guidance by selection history was based on the non-strategic application of memory representations that could be explicitly retrieved and reported.

A traditional dichotomy in attentional control is between goal-directed guidance (strategic orienting based on knowledge of the properties of task-relevant items) and stimulus-driven guidance (non-strategic orienting based on relative physical salience). However, several guidance phenomena lie outside this dichotomy, reflecting the non-strategic influence of memory for previous selective events. These *selection history* effects (Awh, Belopolsky, & Theeuwes, 2012) include contextual cuing (Brooks, Rasmussen, & Hollingworth, 2010; Chun & Jiang, 1998, 2003), inter-trial priming (Kristjansson, Wang, & Nakayama, 2002; Li & Theeuwes, 2020; Maljkovic & Nakayama, 1994; Talcott & Gaspelin, 2020), probability cuing (Geng & Behrmann, 2005; Jiang, Won, & Swallow, 2014), learned distractor rejection (Gaspelin, Leonard, & Luck, 2015; Stilwell, Bahle, & Vecera, 2019; Wang & Theeuwes, 2018), and reward learning (Anderson, 2015; Anderson & Britton, 2019; Hickey, Chelazzi, & Theeuwes, 2010).

For a selection history effect to fall outside the goal-directed/stimulus-driven dichotomy, it is of course important to ensure that the bias is not driven by differences in physical salience. It is also necessary to demonstrate that the bias is non-strategic; otherwise, the effect would simply be an example of learned, goal-directed guidance. Some selection-history paradigms meet this latter criterion by using non-predictive experimental designs. For example, inter-trial priming describes the reaction time (RT) facilitation when a feature value of the target repeats across consecutive trials compared to when it switches to an alternative feature value (e.g., Kristjansson & Asgeirsson, 2019; Kristjansson et al., 2002; Li & Theeuwes, 2020; Maljkovic & Nakayama, 1994; Talcott & Gaspelin, 2020). These paradigms are constructed so that the attributes of the target on the previous trial do not predict the attributes on the current trial. In other paradigms that generate selection history effects, such as contextual cuing or probability cuing, the manipulations *are* predictive of the target attributes and thus have the potential to support an explicit strategy. The criterion of non-strategic guidance is then typically established through an end-of-experiment “awareness” test, in which memory for the manipulated value is probed. If participants cannot explicitly report the value generating the selection-history bias, then they were unlikely to have formed a strategy during the main experiment (but see Giménez-Fernández, Luque, Shanks, & Vadillo, 2023).

Poor end-of-experiment memory performance can also lead researchers to describe the underlying learning mechanism as depending on an implicit form of memory. The claim that selection-history effects depend on implicit memory is common across a wide range of paradigms and phenomena. Such claims have been made in the contextual cuing (Chun & Jiang, 1998, 2003; Tseng & Lleras, 2013), probability cuing (Jiang et al., 2014), inter-trial priming (Maljkovic & Nakayama, 2000), and reward (Anderson, 2015) literatures. Claims of implicit memory often rest on the assumption that the effects derive from a statistical learning mechanism (Turk-Browne, Junge, & Scholl, 2005), in which incidental registration of the properties of previous episodes leaves a memory trace of learned regularities that can influence behavior in the absence of explicit memory.

The general assumption that selection history effects reflect implicit learning raises the question of whether selection history effects are *limited* to implicit forms of memory: Is implicit memory a necessary condition for the type of non-strategic guidance that places a particular learning effect outside the goal-directed/stimulus-driven dichotomy? We argue here that it is not. At the broadest level, explicitly available memory representations are often associated with learned, reflexive behaviors. Consider conditioned taste aversion. After eating a suspicious oyster and falling ill, the subsequent aversion when exposed to the smell or taste of oyster is certainly not based on an explicit strategy to avoid oysters; the aversion is not in any meaningful sense *goal-directed* as conceived in the literature on attention. Explicit recall of the inducing event may not be required for expression of the aversion, but it would be very odd if one were unable to recall the episode of oyster eating or the following period of illness, and vivid explicit memory for the inducing event makes the aversion no less reflexive.

More closely related to attention guidance, the literature on inter-trial priming also provides an indication that the stimulus properties generating non-strategic biases may be explicitly available for report, at least under some circumstances and for some feature dimensions. Inter-trial priming has been observed robustly for both surface-feature repetitions (Maljkovic & Nakayama, 1994) and location repetitions (Maljkovic & Nakayama, 1996). The phenomenon is typically described as depending on an implicit learning mechanism that generates biases independently of strategy (Maljkovic & Nakayama, 1994, 2000; Talcott & Gaspelin, 2020). Note that Maljkovic and Nakayama generally considered implict memory and non-strategic guidance as two sides of the same underlying construct: evidence that the effect was not sensitive to manipuations of strategy led to the claim that the memory representation and its application were “implict”. In contrast, we consider the possibility that non-strategic guidance, as demonstrated in the inter-trial priming paradigm, may be asscoiated with memory representations that can be explictly retrieved and reported.

Evidence consistent with the original Maljkovic & Nakayama conceptualization was obtained by Jiang, Shupe, Swallow, and Tan (2016). They examined target identity repetition effects and observed a reliable inter-trial repetition advantage on search RT. In a surprise test, participants were asked to report the identity of the target on the immediately preceding trial from among four alternatives (see H. Chen & Wyble, 2015a). The proportion of participants reporting the correct item did not reliably exceed chance.[1] Although it is possible that the surprise memory test was simply less sensitive than inter-trial priming (see Meyen, Vadillo, von Luxburg, & Franz, in press), the presence of inter-trial effects in the absence of above-chance memory report is at least suggestive of the dependence of the former on an implict form of memory.

The Jiang et al. test was focused on memory for target identity. This may not have been the optimal dimension for examining a possible dissociation between inter-trial effects and explicit memory. Recent evidence suggests that incidental memory for non-spatial properties of target objects can be impoverished relative to incidental memory for location, with the latter reported quite reliably (H. Chen & Wyble, 2015b; Tam & Wyble, 2023). This rasies the possibility that non-strategic, inter-trial location priming can be supported by location memory that is available for explict retrieval and report. Thus, a stronger test of the implict memory hypothesis in this domain would be to examine inter-trial location priming in combination with a memory test probing explict memory for the location of the target on the preceding trial.

In the present study, we implemented this type of test. Our main goal was to examine inter-trial priming of target location and to test explicit memory for the location of the previous

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[1] Maljkovic and Nakayama (2000) implemented a similar test, except that memory for previous target color and location was tested at intervals of 4-10 trials throughout the entire experiment. In contrast with Jiang et al. (2016), they found that participants could reliably report the “incidental” properties of the previous search target. However, these properties were unlikely to be truly incidental in Maljkovic and Nakayama, as the design created a demand to strategically encode and retain them in preparation for the frequent memory tests.

target. At a general level, we sought to test whether effects of incidental learning and selection history can be based on a non-strategic application of memory representations that can be explicitly retrieved and reported. We focused on two time-scales and levels of abstraction to examine repetition effects: 1) classic inter-trial priming and 2) block-level, category-specific priming. We will refer to these as *inter-trial* effects and category-specific, *inter-block* effects, respectively.

The basic method is illustrated in Figure 1. On each trial of the expeirment, participants saw a cue indicating the category of the target object (e.g., “cat”). Then, they searched through an array of eight natural-object photographs, one of which matched the category cue, and reported the orientation of a secondary feature superimposed on the target (“F” or mirror reversed “F”). For the inter-trial component of the design, target location randomly varied from trial to trial within each block; thus, inter-trial location repetition ocurred on approximately 12.5% of trials. Trials were divided for analysis into location-repetition trials and location-change trials. For the inter-block component of the design, the target objects were organized into 36 different categories, with a target from each category appearing once in each of the 20 blocks of the experiment. Two possible target locations were chosen for each catgeory, and target location varied pseudo-randomly from block-to-block. For example, when searching for a cat, in some blocks the cat target appeared in the same location as the cat target had appeared in the previous block, and in some blocks it appeared in the different location. This allowed us to examine longer-term repetition effects, structured by category. In addition to this basic design, the target objects in each category also had two possible colors (e.g., grey cats and tan cats). Color could repeat or change within a category from one block to the next, allowing us to

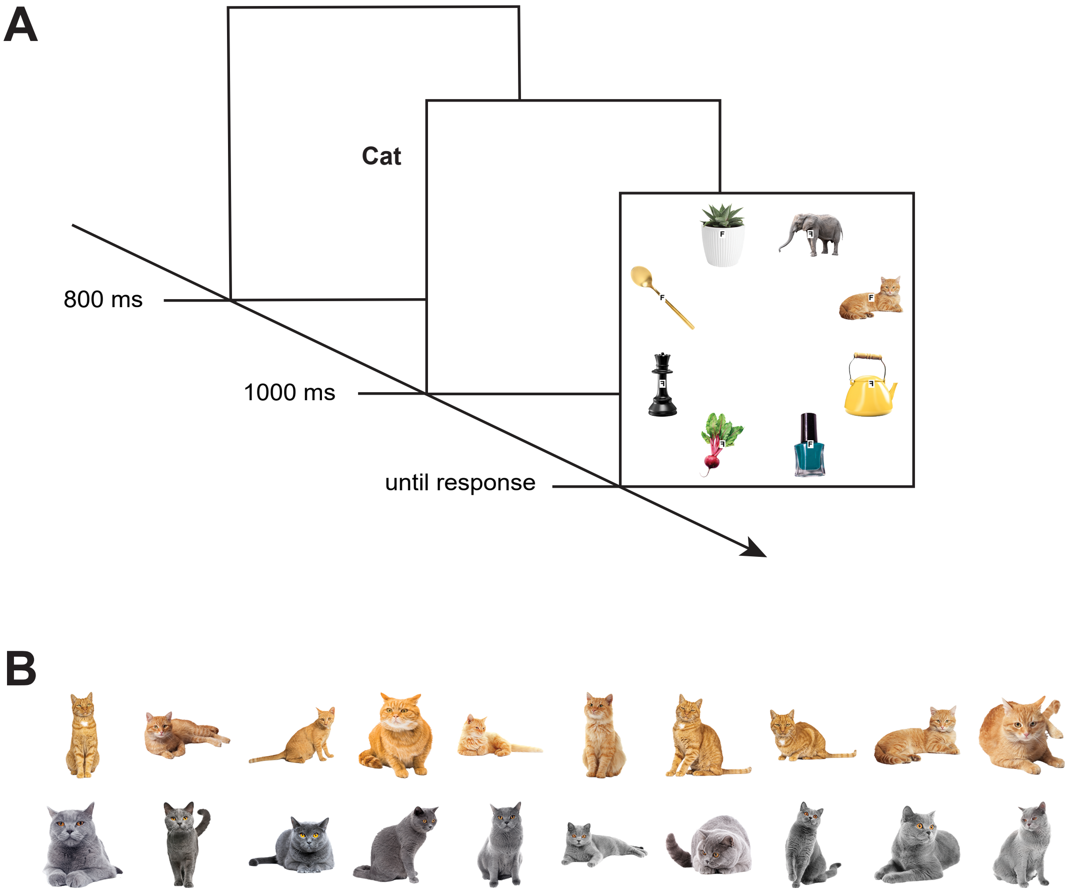

Figure 1. Overview of method in Experiment 1. **A**. In the visual search task, participants saw a label describing the target category, followed by a search array. They searched for the object that matched the label and reported the orientation of a superimposed letter "F". **B**. The set of target object stimuli for a sample category. Note that due to licensing restrictions, the object photographs in this figure differ slightly from those used in the experiments.

probe longer-term color-repetition effects and the interaction between color repetition with location repetion.

<< Insert Figure 1 about here >>

Using this basic design in Experiment 1, we sought to observe both classic inter-trial repetition effects and category-specific, inter-block repetition effects on RT. Experiments 2-4 then examined whether participants could explicitly report the feature values supporting those incidental repetition effects. Experiments 2 and 3 probed memory for the properties of the target object on the immediately preceding trial. Participants completed a single block of the search task. This was followed by a single-trial, surprise test probing memory for either the location of the target or the color of the target on the preceding trial. Experiment 4 probed memory for the category-specific attributes of the targets in the preceding block. Participants completed two blocks of search before the memory test. In these two blocks, the two targets in each category appeared in both possible locations and in both possible colors. On the surprise memory test, participants were given a category label cue and were asked to report the location or color of that target object type in the immediately preceding block. They did this for all 36 categories.

Experiments that have observed poor explicit report of the feature values driving selection history effects have typically used abstract stimuli, such as alphanumeric characters or meaningless shapes. Moreover, these stimuli are typically repeated throughout the experiment, potentially introducing substantial proactive interference. Here, we sought to provide a strong test of the implicit memory hypothesis by using real-world object stimuli that make contact with existing representations of meaning (Brady, Störmer, & Alvarez, 2016; Draschkow, Wolfe,

& Vo, 2014; Josephs, Draschkow, Wolfe, & Vo, 2016), and, further, we used a task that required participants to process the meanings of objects, because the cue was categorical (Yang & Zelinsky, 2009). In addition, each target object was a unique exemplar from a particular category (there was no repetition of target objects), reducing the possibility of proactive interference. Under these types of conditions, explicit memory for the visual properties of objects can be extraordinarily good (Brady, Konkle, Alvarez, & Oliva, 2008; Hollingworth, 2005), even when participants have no demand to remember them (H. Chen et al., 2019; W. J. Chen & Howe, 2017; Sasin, Markov, & Fougnie, 2023; Williams, Henderson, & Zacks, 2005). Thus, we predicted that for the types of natural object stimuli that characterize everyday visual perception and memory, we would observe reliable inter-trial effects and we would also observe that the incidentally encoded stimulus values generating those selection history effects could be reliably retrieved and explicitly reported. Note that we are not claiming that explicit retrieval during a search trial is *required* for expression of the selection history effect itself, only that selection history effects in the present paradigm are likely to depend on memory representations that are available for report when memory is probed directly.

Experiment 1

Method

Participants. Participants were recruited from the University of Iowa community, were between 18 and 30 years of age, and received course credit for their participation. All participants reported normal or corrected-to-normal vision. Each participant completed only one of the experiments. All human subjects' procedures were approved by the University of

Iowa Institutional Review Board.

The present study used a novel inter-trial design (with naturalistic stimuli and a categorical search task), and so there are no published effects on which to base a power analysis. Thus, we targeted a relatively large N of at least 40. For the type of within-subjects contrast used for the inter-trial analysis here, a sample of 40 has 80% power to detect a medium-sized effect of η_p^2 = .18. Forty-seven participants completed the experiment. Five were eliminated for failing to achieve 85% accuracy, leaving 42 participants in the analysis. Due to a coding error, we did not collect gender information, though participants' names indicated a gender distribution of 24 female and 18 male.

The data and materials for the experiments reported here are available upon request. None of the experiments was preregistered.

Apparatus. The experiment was conducted online. It was programmed with OpenSesame software (Mathot, Schreij, & Theeuwes, 2012) and hosted on a JATOS server maintained by the University of Iowa. Participants were instructed to complete the experiment using either a desktop or laptop computer.

Stimuli. The stimulus set consisted of 720 unique target object photographs and 150 unique distractor object photographs. These were gathered from a variety of sources, including existing object databases and internet searches. The target photographs were organized into 36 familiar real-world categories: 18 artifact and 18 natural (see the Appendix for a complete list of categories). Most categories were defined at the basic level (e.g., "cat"); a few were defined at the subordinate level (e.g., "dress shirt"). Within each category, there were 20 exemplar photographs. Ten of the exemplars appeared in one general color, and ten appeared in a different general color (See Figure 1B). Both colors were plausible for the category of object (see the Appendix for a complete list of the two colors for each category). Each of the 150 distractor objects came from a different category (75 artifact, 75 natural) that did not overlap with the 36 experimental categories.

Because of variation in the monitor sizes and viewing distances, we report stimulus dimensions in pixels. Object stimuli were scaled to fit within a 150 x 150 pixel region, presented against a white background. In the visual search task, eight objects were presented on a virtual circle (300-pixel radius) around central fixation. The eight locations were evenly spaced around the virtual circle, with four to the left of the vertical meridian and four to the right. Every search display contained one member of the cued category (i.e., all trials were target-present trials). The distractor objects on each trial were chosen from the set of 150 distractor images. Each array had four artifacts and four natural objects. For example, if the target was an artifact, there were three artifact distractors (chosen randomly without replacement) and four natural object distractors (also chosen randomly without replacement).

Each target category was assigned two possible locations in the search array. These were determined randomly for each category with the constraints that one had to be in each hemifield and they could not be adjacent. Across the 20 blocks, targets in a category appeared in each of the two possible locations 10 times. Similarly, the targets in a category appeared in each of the two colors 10 times. The order of locations and colors across blocks was randomized for each category. All distractor objects were assigned random locations. A small, black letter “F” on a white background (Arial font, subtending 11 X 15 pixels) was superimposed centrally on each array object, with the orientation of the “F” (facing left or facing right) selected randomly. The cue that appeared before each search array was a word presented in Arabic font describing the category of the target object (e.g., “cat”).

Procedure. After clicking the study link, participants provided informed consent. They were then given instructions for the visual search task. The sequence of events in a trial is illustrated in Figure 1A. Each trial began with a centrally presented “Press SPACEBAR to start next trial” screen. Once the participant pressed the spacebar, there was a 400-ms delay, followed by the category cue label presented centrally for 800 ms. After cue offset, there was a 1000-ms blank delay before the presentation of the search display, which remained visible until response (see Figure 1A). Participants searched for the object matching the category label and reported the orientation of the “F” superimposed upon it, using the “P” button to report a right-facing “F” (i.e., standard) and the “Q” button to report a left-facing “F” (i.e., mirror-reversed). Participants were instructed to make this response as quickly and as accurately as possible. Incorrect responses were followed by a frowny emoticon for 500 ms. Correct responses were followed by a smiley emoticon for 300 ms.

Participants first completed 10 practice trials, searching for objects from categories that were not used in the main experiment. They then completed 20 blocks of 36 trials. For the inter-trial analysis, there was a 12.5% chance that the target location repeated from Trial N-1 to Trial N. Trials were divided into location-repeat trials and location-switch trials. For the inter-block analysis, there were four possible conditions relating the current search within a category to the search that ocurred for that category in the previous block: Location Repeat, Color Repeat, Both Repeat, and Neither Repeat. For example, assume that in Block 1 the target cat was tan and in location 1. In Block 2, the target cat could have been grey and in location 1

(Location Repeat), tan and in location 2 (Color Repeat), tan and in location 1 (Both Repeat), or grey and in location 2 (Neither Repeat). With the randomization of both location and color, each condition had a probability of 0.25.

Participants completed 720 trials, one for each of the 720 target objects. The entire experiment lasted approximately one hour.

Data Processing. In all experiments, the critical measure was mean RT in the search task as a function of repetition condition. Data were divided either according to the inter-trial analysis (location repeated, switched) or according to the inter-block analysis (category-based location repetition X color repetition). In each, the analysis was limited to correct search trials, and trials with RTs shorter than 250 ms, longer than 6000 ms, or more than 2.5 standard deviations from the participant's mean in each condition were removed from the analysis. A total of 8.0% of trials was eliminated from the inter-trial analysis and 8.0% from the inter-block analysis. The pattern of results was not influenced by RT trimming in any experiment in this study. Adjusted η_p^2 values accompany each statistical test (Mordkoff, 2019).

Results

The results of Experiment 1 are reported in Figure 2.

<< Insert Figure 2 about here >>

Search Accuracy. Overall search accuracy was 95.2% correct. For the inter-trial analysis, there was no reliable difference in accuracy between location-repeat trials (95.3%) and location-switch trials (95.2%), $F(1,41) = 0.03$, $p = .875$, adj $\eta_p^2 = -.024$. For the inter-block analysis, search accuracy did not differ among the four conditions (Both Repeat: 95.0%, Color Repeat: 95.2%, Location Repeat: 95.4%, Neither Repeat: 95.1%), $F(3,123) = 0.77$, $p = .515$, adj

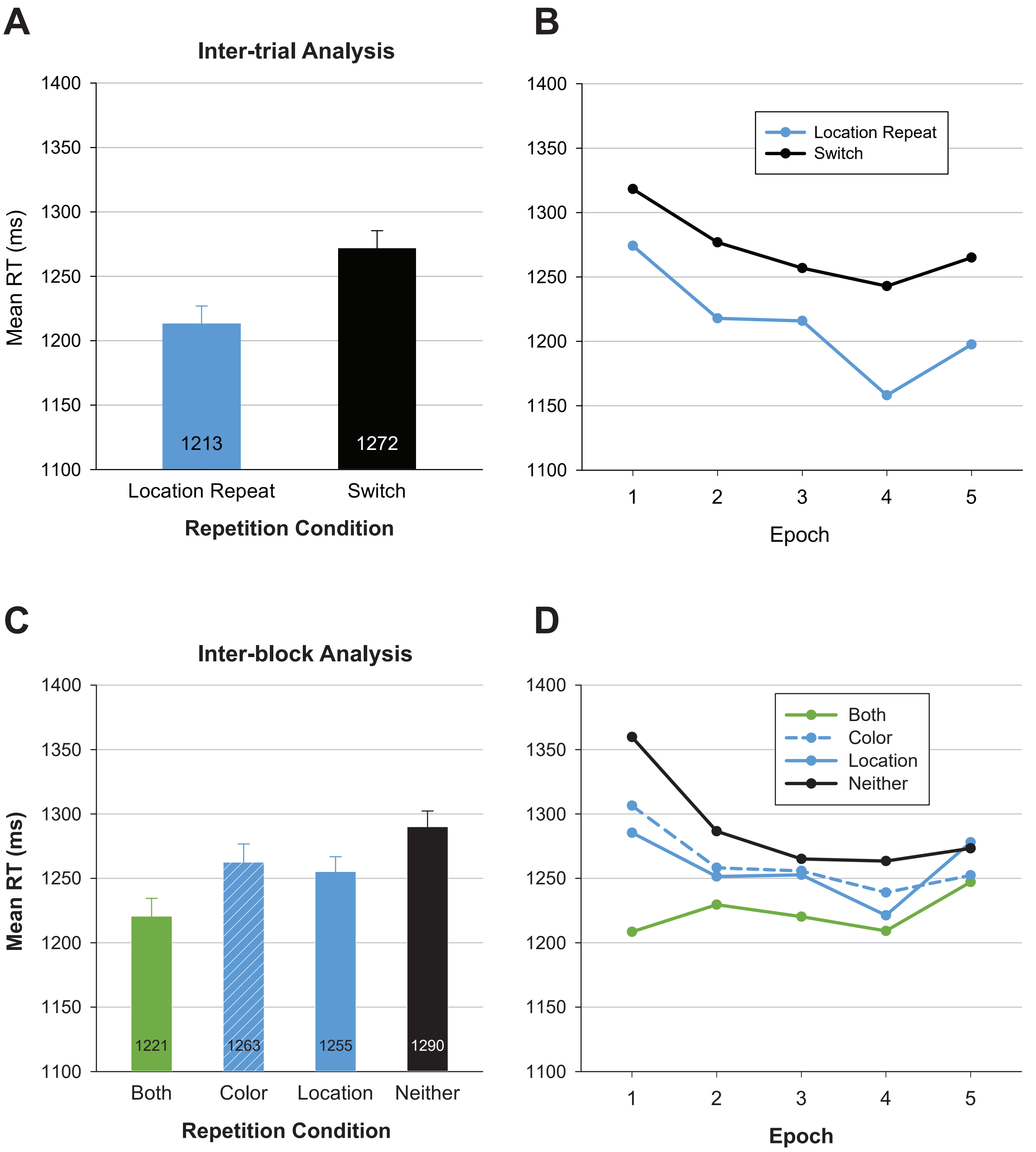

Figure 2. Experiment 1 results. **A**. Inter-trial analysis probing the repetition of search target location from trial N to trial N + 1. The data as a function of search epoch appear in **B**. **C**. Inter-block analysis probing category-specific repetition of target location and color. The data as a function of search epoch appear in **D**. Error bars are condition-specific, within-subject 95% confidence intervals (Morey, 2008).

η_p^2 = -.006.

Manual RT: Inter-trial Analysis. We first tested for the presence of a classic inter-trial effect of target location repetition from trial N-1 to trial N. We observed a robust inter-trial repetition effect (Figure 2A), with mean RT on location-repeat trials (1213 ms) reliably lower than mean RT on location-switch trials (1272 ms), $F(1,41) = 37.0$, $p < .001$, adj η_p^2 = .462.

We also examined how the inter-trial repetition effect evolved over the course of the experiment (Figure 2B). The 20 blocks were divided into five epochs of four blocks each. As is evident from the figure, the inter-trial effect was observed consistently throughout the experiment. The data were entered into a 2 (location repetition) X 5 (epoch) repeated-measures ANOVA. There was a reliable main effect of inter-trial repetition, $F(1,41) = 40.23$, $p < .001$, adj η_p^2 = .483, and a reliable main effect of epoch, $F(4,164) = 8.33$, $p < .001$, adj η_p^2 = .149, but no reliable interaction, $F(4,164) = 1.17$, $p = .328$, adj η_p^2 = .004.

Finally, we examined whether a repetition effect could be observed based on trials occurring earlier than N-1. We found a reliable repetition advantage (mean difference = 52 ms) when location repetition was defined relative to the N-2 target location, $F(1,41) = 27.0$, $p < .001$, adj η_p^2 = .382. There was no reliable repetition advantage (mean difference = 14 ms) when location repetition was defined relative to the N-3 target location, $F(1,41) = 1.35$, $p = .252$, adj η_p^2 = -.024.

Manual RT: Inter-block Analysis. We then tested for the presence of category-specific, inter-block repetition effects for location and color (Figure 2C). The mean RT data were entered into a one-way repeated measure ANOVA with four levels (repetition condition: Both, Color, Location, Neither). There was a reliable effect of repetition condition, $F(3,123) = 19.55$, $p < .001$, adj η_p^2 = .306. Planned contrasts revealed that RTs were faster when location repeated (1255 ms) than when neither feature repeated (1290 ms, $p < .001$), when color repeated (1263 ms) than when neither feature repeated ($p = .038$), and when both features repeated (1221 ms) than when neither feature repeated ($p < .001$). Further, RTs were faster when both features repeated compared to when only location ($p = .003$) or color repeated ($p < .001$).

We also examined how the inter-block repetition effect evolved over the course of the experiment (Figure 2D). The 19 blocks (2-20) were divided into five epochs of four blocks each, with the last epoch containing three blocks. As is evident from the figure, the inter-block effects were observed most robustly in the first epoch, before stabilizing in later epochs. The data were entered into a 4 (repetition condition) X 5 (epoch) repeated-measures ANOVA. There was a reliable main effect of repetition condition, $F(3,123) = 17.42$, $p < .001$, adj η_p^2 = .281, a reliable main effect of epoch, $F(4,164) = 2.84$, $p = .026$, adj η_p^2 = .042, and a reliable interaction, $F(12,492) = 2.79$, $p = .001$, adj η_p^2 = .041.

Discussion

Robust inter-trial repetition effects were observed for location repetition from trial N-1 to trial N. This result replicates previous inter-trial effects but using natural object stimuli and a categorical search task.[2] In addition, we observed category-specific, inter-block repetition

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[2] A topic of debate in the literature on inter-trial repetition is whether the source of the effect is on the guidance of attention (Maljkovic & Nakayama, 1996; Talcott & Gaspelin, 2020) or on post-selection decision processes (Hilchey, Antinucci, Lamy, & Pratt, 2019). Our present method cannot distinguish between these two possibilities. However, we have conducted an eye tracking experiment examining a different learning phenomenon (Bahle, Kershner, & Hollingworth, 2021) that used stimuli and a search task that were almost identical to the present stimuli and search task. In that study, the effect of learning was limited to the guidance operation: i.e., the elapsed time until first fixation on the target object. Thus, our working assumption is that the present inter-trial effect is also likely to reflect differences in guidance processes between repeat and switch trials, although confirming this assumption will acquire additional work.

effects for both location and color. For these categorical effects, location and color repetition were broadly additive, indicating that category-specific retrieval of properties from multiple different dimensions jointly influences attention guidance. Note that both the inter-trial and inter-block effects were observed in a paradigm in which the properties of the preceding target(s) did not predict the properties of the current target, making it unlikely that the effects were based on an explicit strategy. In addition, the effects were observed consistently throughout multiple blocks of the experiment, rather than being limited to the early blocks. That is, the effects persisted even after participants had substantial experience with the non-predictive structure of the experiment, again making it unlikely that repetition effects were based on explicit strategy.

Experiment 2

Having demonstrated a reliable *inter-trial* location repetition effect in Experiment 1, in Experiment 2A we sought to test whether participants have explicit access to memory for the location of the target on the previous trial. As discussed in the Introduction, several studies that have examined memory for previous target properties have indicated that target location is retained more robustly than other, non-spatial features of objects, with report of the latter often close to chance (H. Chen & Wyble, 2015b; Tam & Wyble, 2023). To probe memory for non-spatial features within the context of the current search paradigm, we also tested memory for the color of the target on the previous trial in Experiment 2B. In both sub-experiments, participants completed one block of 36 search trials. Immediately following the 36th trial, they completed a surprise, forced-choice memory test probing memory for either the location or color of the previous target. The surprise-test methods are illustrated in Figure 3.

<< Insert Figure 3 about here >>

Method

Participants. We set a target of at least 30 participants in each of Experiments 2A and 2B. All participants were between 18 and 30 years of age and reported normal or corrected-to-normal vision. Participants were recruited using the Prolific system (www.prolific.com). They received compensation for their participation at the rate of $12/hour. Thirty-two participants completed Experiment 2A, and 38 completed Experiment 2B. Participants were excluded from analysis if they failed to achieve 85% accuracy in the search task or if they responded incorrectly to the search task on the 36th trial. Two participants were excluded from Experiment 2A, leaving an N of 30 (11 female, 19 male), and seven were excluded from Experiment 2B, leaving an N of 31 (13 female, 17 male, 1 not reporting).

Stimuli and procedure. The stimulus set and method were the same as in Experiment 1, except as noted.

Participants completed one block of 36 trials of search, immediately followed by the surprise memory test. For the test of previous target location (Experiment 2A), after responding on the 36th trial and receiving feedback, an eight-alternative memory test display was presented consisting of eight circles (at each of the possible locations) and the text “Enter the location of the LAST OBJECT you found.” Each circle contained a digit from 1-8 in the order depicted in Figure 3. Participants entered the number on the keyboard corresponding to the selected location. This response ended the experiment.

For the test of previous target color (Experiment 2B), the method was the same, except

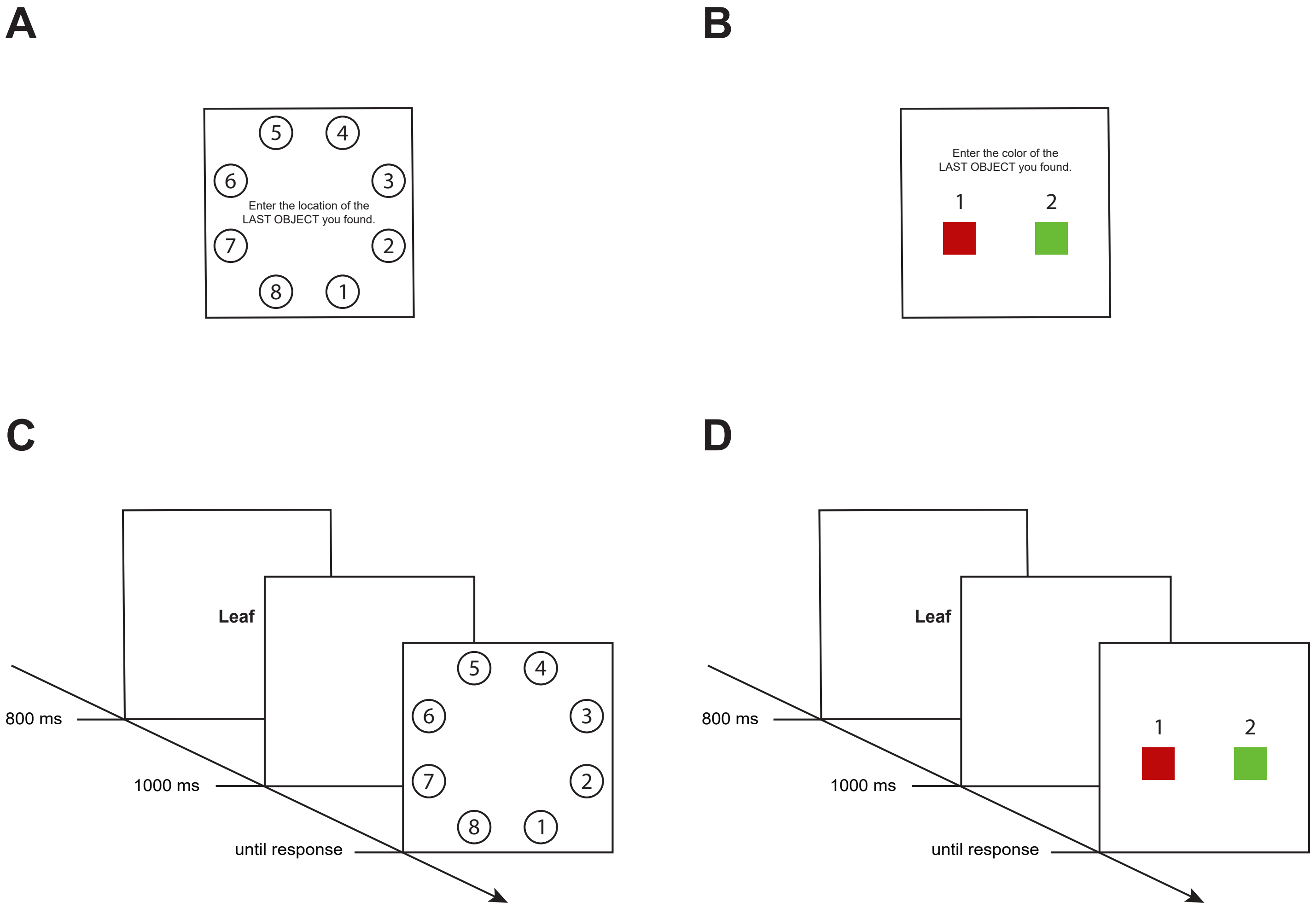

Figure 3. Experiments 2-4 surprise memory test methods. For Experiments 2 and 3, immediately after responding to the 36th trial of search, participants completed a single-trial test in which they were asked to report either the location (**A**, Experiments 2A and 3A) or the color (**B**, Experiment 2B and 3B) of the last target object they found. In Experiment 4, after two blocks of search, participants completed 36 trials (one for each category), in which they reported either the location (**C**, Experiment 4A) or the color (**D**, Experiment 4B) of the target from that category the last time they found one.

the test required two-alternative color discrimination. The test screen contained two color squares (128 x 128 pixels), with the numbers 1 and 2 above them, and the text “Enter the color of the LAST OBJECT you found.” Participants entered the number corresponding to the selected color. The color alternatives were the two possible colors in the category of the 36th target item. Specifically, two exemplars of different colors were selected for each category (e.g., one green leaf exemplar and one red leaf exemplar), and participants saw one of these two versions, randomly selected, as a target in the search block of 36 trials. For each of the two exemplars, average color across the object was calculated (excluding regions not containing the primary color). These two average colors were the two alternatives, randomly assigned to either the left or right position in the test display. Thus, if the 36th trial contained a green leaf target, the two alternatives would have been green and red. Note that the random assignment of exemplar colors in the search session precluded any systematic effects of color plausibility, since the two colors from a category were equally likely to be properties of the target on the 36th trial. Because trial order was randomized in the search block (as in Experiment 1), the target item appearing on the 36th trial was randomly selected from among the 36 categories. The full set of color values is listed in the Appendix.

The entire experiment lasted approximately 10 minutes.

Results

Search Accuracy and RT. Overall search accuracy was 96.2% correct in Experiment 2A and 96.4% correct in Experiment 2B. We did not expect to observe a statistically reliable location repetition effect with such a small number of trials (36, compared with 720 in Experiment 1). However, for the sake of completeness, we pooled the data from Experiments

2A and 2B and divided trials into location-repeat and location-switch. Repeat trials (1346 ms) were numerically faster than Switch trials (1373 ms), but that difference did not reach significance, $F(1,59) = 0.58$, $p = .449$, adj $\eta_p^2 = -.007$.

Memory Test Accuracy. For the eight-alternative location memory test, 83.3% of participants (25 of 30) correctly selected the location of the last search target. This percentage of correct responses was reliably higher than the 12.5% expected by chance, $\chi^2(1) = 137.62$, $p < .001$.

For the two-alternative color memory test, 87.1% of participants (27 of 31) correctly selected the color of the last search target. This percentage of correct responses was reliably higher than the 50% expected by chance, $\chi^2(1) = 17.67$, $p < .001$.

Discussion

The memory test results in Experiment 2A demonstrated that participants could reliably report the location of the search target from the immediately preceding trial. This indicates that memory for the feature value responsible for generating the inter-trial repetition effects in Experiment 1 of the present study, target location, was generally available for retrieval and explicit report. Non-strategic, selection history effects need not be limited to implicit forms of memory. In addition, we observed that participants could reliably report the color of the search target on the immediately preceding trial (Experiment 2B).

Experiment 3

We have interpreted the results of Experiments 2A and 2B as indicating that participants could explicitly retrieve and report the location and color of the immediately preceding search target. It is possible, however, that participants' selection on the surprise test was driven, instead, by implicit priming from the previous trial. For example, when presented with the circular array of test location options in Experiment 2A, the selective behavior on the preceding trial may have implicitly biased attention toward the previous target location, leading participants to generate a correct response on the surprise test despite having no explicit memory for the previous search target location (i.e., guessing). To address this possibility, we conducted Experiments 3A and 3B. These were identical to Experiments 2A and 2B, respectively, except that after the surprise memory test response, participants were asked to rate the quality of their memory for the previous search target on a 5-point scale, where 1 corresponded to "No memory. I guessed" and 5 to "I explicitly remembered the specific object I found." We expected that memory ratings following correct responses would be consistent with explicit recall.

Method

Participants. Thirty-five participants completed Experiment 3A, and 32 completed Experiment 3B. Five participants were excluded from Experiment 3A (for the same reasons as described in Experiment 2), leaving an N of 30 (15 female, 15 male). No participants were excluded from Experiment 3B (15 female, 16 male, 1 not reporting).

Stimuli and procedure. The stimuli and procedure were identical to those in Experiments 2A and 2B, with the following exception. Immediately after responding to the surprise memory test, a new screen was presented with the following text: "Now assess your memory for the last object you found on the scale below." Immediately below this text were the numbers 1 through 5. Anchored to the "1" option was the text, "No Memory. I Guessed."

Anchored to the “5” option was the text, “I explicitly remembered the specific object I found.” Entry of an integer value between 1 and 5 ended the experiment.

Results

Search Accuracy and RT. Overall search accuracy was 95.9% correct in Experiment 3A and 95.8% correct in Experiment 3B. Again, for the sake of completeness, we pooled the data from Experiments 3A and 3B and divided trials into location-repeat and location-switch (two participants were eliminated due to an empty cell in the repeat condition). Repeat trials (1253 ms) were numerically faster than Switch trials (1283 ms), but that difference did not reach significance, $F(1,59) = 0.91$, $p = .330$, adj $\eta_p^2 = -.001$.

Memory Test Accuracy and Memory Quality Rating. For the eight-alternative location memory test, 76.7% of participants (23 of 30) correctly selected the location of the last search target. This percentage of correct responses was reliably higher than the 12.5% expected by chance, $\chi^2(1) = 112.93$, $p < .001$. Critically, participants who answered correctly reported memory quality values on the high end of the scale, with a mean value of 4.34 (SD = 0.79).

For the two-alternative color memory test, 84.3% of participants (27 of 32) correctly selected the color of the last search target. This percentage of correct responses was reliably higher than the 50% expected by chance, $\chi^2(1) = 15.13$, $p < .001$. Memory quality values for correct responses were again on the high end of the scale, with a mean value of 4.30 (SD = 0.99).

Discussion

The surprise memory test results replicated Experiments 2A and 2B. When asked to report the quality of their memory for the immediately preceding search target, participants in both sub-experiments tended to produce values near the high end of the scale ("I explicitly remembered the specific object I found."). This result is inconsistent with an alternative explanation of the surprise test results in which an implicit bias led to accurate performance despite the absence of explicit memory. Instead, it is consistent with our assumption that participants could explicitly retrieve and report the location and color of the immediately preceding search target.

Experiment 4

Having demonstrated category-specific, *inter-block* repetition effects in Experiment 1, in Experiment 4 we sought to test whether participants have explicit access to memory for the feature values in each category generating those effects. Participants completed two blocks of search in which the two targets from a category appeared in both possible colors and in both possible locations, equating exposure to these values. Then, participants completed 36 test trials, one for each category. The surprise-test methods are illustrated in Figure 3. They received a category label and were asked to report either the location (Experiment 4A) or the color (Experiment 4B) of the target, the last time they found that object type in the immediately preceding block. In this method, we tested the form of memory that would underly the category-specific inter-block repetition effect (memory for the *last* location and *last* color when a member of that category was the target).

Method

Participants. We set a target of at least 20 participants in each of Experiments 4A and 4B. This was lower than the target N in Experiment 2, since we collected 36 trials of data from each participant rather than just one. All participants were between 18 and 30 years of age and reported normal or corrected-to-normal vision. Participants were recruited using the Prolific system and received compensation at a rate of $12/hour. Twenty-four participants completed Experiment 4A, and 26 completed Experiment 4B. Participants were excluded from analysis if they failed to achieve 85% accuracy in the search task. Three participants were excluded from Experiment 4A, leaving an N of 21 (14 female, 7 male), and one was excluded from Experiment 4B, leaving an N of 25 (18 female, 6 male, 1 not reporting).

Stimuli and procedure. The stimuli and procedure were the same as in Experiment 2, with the following changes. Participants completed two blocks of search before the surprise memory test. In the search blocks, they received equal exposure to each of the two colors and two locations for each category. Thus, the location and color for each category switched from the first block to the second block (i.e., there were no Repeat trials).

For the location memory test (Experiment 4A), after completing the last trial of search, a screen was displayed that explained the memory test with the following text, “We will now test your memory for the locations of the objects you found. We will show you a series of category labels and eight possible locations. Recall the location of that category of object the LAST TIME you found one in the IMMEDIATELY PRECEDING session. Press the number key corresponding to the matching location.” Participants continued to the test trials. On each trial, participants pressed the spacebar to initiate the trial. There was a 400-ms delay before the presentation of the category label for 800 ms, a blank delay of 1000 ms, and the test display. The display was the same as in Experiment 2A, but without the central text. Participants entered the number on the keyboard corresponding to the selected location.

For the color memory test (Experiment 4B), the search session was identical to Experiment 4A. The test instructions were modified for the test of color rather than location. The sequence of events in a trial was the same as in Experiment 4A. The test display on each trial was similar to Experiment 2B, with two color patch options. The color alternatives were constructed in the same manner as in Experiment 2B.

In each experiment, participants completed 36 memory test trials, with the order of categories randomized. The entire experiment lasted approximately 15 minutes.

Results

Search Accuracy. Overall search accuracy was 95.6% correct in Experiment 4A and 96.1% in Experiment 4B.

Memory Test Accuracy. For the eight-alternative location memory test in Experiment 4A, participants chose the correct location (i.e., the location from the second search block) on 35.1% of trials, and they chose the first-block location on 17.1% of trials. Averaging across the remaining six locations, they selected any individual location that had not contained a target from that category on 8.0% of trials. The percentage of correct, second-block reports was reliably higher than the percentage of first-block reports, $t(20) = 4.89$, $p < .001$, indicating that participants had specific access to the location of the target the last time it appeared. In addition, the percentage of first-block reports was reliably higher than the percentage for any given “other” location, $t(20) = 5.90$, $p < .001$, indicating that participants sometimes retrieved the first-block location rather than the second-block location.

For the two-alternative color memory test in Experiment 4B, overall accuracy for selecting the color of the category from the second block of search was 61.9%, which was significantly greater than chance of 50%, *t*(24) = 6.00, *p* < .001.

Discussion

The memory tests in Experiment 4 demonstrated that participants had explicit memory for the last category-specific target location and color, at least on some proportion of trials. This suggests that memory for the feature values responsible for generating category-specific, inter-block repetition effects in Experiment 1 were often available for retrieval and explicit report. Accuracy did not approach the levels observed in Experiments 2 and 3. However, this is not surprising given the differences in retention interval, the interference generated by intervening trials (an average of 36 trials between last observation and test in Experiment 4, versus one trial in Experiments 2 and 3), and the need to use category as a retrieval cue in Experiment 4.

General Discussion

Selection History and Implicit versus Explicit Memory

In the present study, we tested whether selection history effects in attentional control are limited to implicit forms of memory or whether such effects can also be driven by memory representations than are explicitly available for retrieval and report. Specifically, we examined whether participants could reliably report the object features functional in producing non-predictive, inter-trial target repetition effects (Maljkovic & Nakayama, 1994, 1996; Talcott & Gaspelin, 2020). Repetition effects were assessed at two levels: 1) classic, inter-trial repetition of target location from trial N-1 to trial N and 2) category-specific repetition of location and color from one block to the next. At both levels, repetition advantages on search RT were observed consistently throughout Experiment 1. Critically, Experiments 2-4 found that both the inter-trial effects and category-specific, inter-block effects were based on explicitly reportable memory for the relevant target values. For the inter-trial effect, participants very accurately reported both the location and the color of the target object on the immediately preceding trial. For the inter-block effect, participants reported, at levels reliably above chance, both the location and the color of the target from each category that had appeared in the immediately preceding block. The data demonstrate that selection history effects need not be limited to implicit forms of learning and memory. Such effects can be driven, non-strategically, by memory for target attributes that can be explicitly retrieved and reported.

Although we have shown that the information underlying the present inter-trial effects could be retrieved and reported on the surprise memory tests, this does not mean that explicit retrieval was necessary to *produce* the type of inter-trial effect observed here. That is, just because the feature values generating the effect could be retrieved and reported when given a direct retrieval cue does not necessarily demonstrate that they were explicitly retrieved during the normal course of visual search or that explicit retrieval was required to generate the inter-trial effect. The present data therefore do not necessarily challenge the idea that inter-trial effects tend to be based on a form of “passive” and “automatic” priming (Maljkovic & Nakayama, 1994). However, the fact the feature values supporting the inter-trial effect could be retrieved and reported when cued directly clearly demonstrates that visual memory representations supporting the inter-trial effects observed here cannot be reasonably described as implicit memory representations.

Converging evidence comes from the literature on contextual cuing. When naturalistic scene images provide the contexts that cue target location—instead of random arrays of similar, simple shapes—robust contextual cuing effects are observed (Brockmole, Castelhano, & Henderson, 2006), and participants perform very well on end-of-experiment memory tests of scene-to-target-location associations (Brockmole & Henderson, 2006b). Importantly, the learned bias observed with natural scenes appears to have a reflexive component, rather than just indicating a learned strategy. In Brockmole and Henderson (2006a), natural scene images were unexpectedly mirror-reversed after participants had learned consistent target locations. The first eye movement during search was much more likely to be directed to the associated *screen* location than to the associated *scene* location, indicating that participants had acquired an automatic bias to execute a particular motor response (i.e., a saccade vector) upon identification of each scene.

Additional converging evidence comes from Kershner and Hollingworth (2023). In that study, we employed a category-dependent learning design. In the search task, some target object categories were assigned to a consistent attribute condition (e.g., target location or color were constant across blocks) and others to a randomized attribute condition (e.g., location or color randomly varied across blocks). We observed a categorical cuing effect, in which search times were reliably lower when a category was associated with consistent target attributes, akin to the contextual cuing effect observed when particular arrays or scenes are associated with consistent target attributes (Brockmole & Henderson, 2006b; Chun & Jiang, 1998). As in the present study, we examined explicit memory for the attributes functional in producing the effect. Participants could reliably report the repeated colors and locations for each category at the end of the experiment. They could also accurately report the color and location for each item after a single exposure to one search target in each of the 42 categories.

From these combined results, it is clear that for unique, natural object stimuli, robust access to the properties of previous search targets is available across a range of retention intervals and conditions: For the object that had been the target on the immediately preceding trial (Experiments 2 and 3; H. Chen et al., 2019; W. J. Chen & Howe, 2017; Sasin et al., 2023), for all of the target objects that had appeared within a block of 42 trials (Kershner & Hollingworth, 2023; see also Williams et al., 2005), for the *most recently* presented object in a category when that category had been the target of search multiple times (Experiment 4), and for the category-specific properties of objects repeated across an entire experiment (Kershner & Hollingworth, 2023). In each of these cases, there was no demand to remember the target object features beyond the current trial, as the memory tests were unexpected, suggesting that the incidental encoding of target object features reliably leads to explicitly available memory representations.

These results contrast with evidence indicating that the properties, and particularly the non-spatial properties, of the immediately preceding search target are remembered poorly, if at all (H. Chen & Wyble, 2015a, 2015b, 2016; Tam & Wyble, 2023), a phenomenon that has been termed “attribute amnesia.” In particular, the results of Experiments 2 and 3 do not demonstrate any pattern of performance that could plausibly be termed “amnesic”, with approximately 80% of participants correctly choosing the immediately preceding target location (from eight alternatives) and approximately 85% of participants correctly choosing the immediately preceding target color (from two alternatives). These results are consistent with other studies demonstrating that when unique, natural objects are used as stimuli (instead of repeated alphanumeric characters), memory for the properties of the previous search target supports robust discrimination performance (H. Chen et al., 2019; W. J. Chen & Howe, 2017; Sasin et al., 2023), and there is minimal difference between performance on the surprise test and performance on subsequent, intentional encoding trials (i.e., no evidence of relative "amnesia").

The present surprise-test results were particularly strong, because participants could not reliably use familiarity to support discrimination performance, since the target stimulus was never re-presented at test. That is, we used relatively abstract depictions of the feature alternatives (see Figure 3). For location memory, instead of presenting the original target image at possible locations, circles were presented at all possible locations. For color memory, homogeneous color squares were presented instead of naturally colored objects. The use of abstract representations of the feature alternatives strongly increases the probability that memory performance was driven, not by a feeling of familiarity, but rather by explicit retrieval of the episodic content of the previous search trial. Consistent with this assumption, participants in Experiments 3A and 3B rated their memory for the immediately preceding search target on a 5-point scale (from 1 "No memory. I guessed" to 5 "I explicitly remembered the specific object I found"), and these ratings tended to fall at the high end of the scale (mean rating for location memory and for color memory of approximately 4.3).

The difference between the present study and paradigms showing poor memory on various forms of explicit tests is likely to be the choice of stimuli. Highly limited explicit memory for the properties driving selection history effects (H. Chen & Wyble, 2015a; Chun & Jiang, 1998) appears to be restricted, primarily, to abstract stimuli such as alphanumeric characters. These stimuli have properties that make them suboptimal for drawing general conclusions about mechanisms of learning and attention guidance, particularly when those conclusions involve claims about impoverished explicit memory. First, alphanumeric stimuli tend to be highly similar to each other. They have relatively simple structure and form, and, compared with natural objects, they have fewer dimensions that discriminate them (see Brady, Stormer, & Alvarez, 2016). For comparison, consider the cat stimuli shown in Figure 1. Even though these all belong to the same basic-level category, there is still quite extensive variation in visual form. Second, although alphanumeric stimuli can be categorized, they do not make contact with the same wealth of existing conceptual, functional, and episodic knowledge available for natural objects, potentially limiting the elaborative connections available to support explicit memory (see Brady & Störmer, 2024). Third, studies that have found poor explicit memory have tended to repeat alphanumeric stimuli during the experiment, often thousands of times, potentially creating extensive proactive interference.

In sum, evidence of impoverished explicit memory in inter-trial priming (Jiang et al., 2016; Kristjansson, Vuilleumier, Malhotra, Husain, & Driver, 2005) and other selection history tasks (e.g., Chun & Jiang, 1998; Jiang et al., 2014) often fails to generalize to naturalistic stimuli (the present study; Brockmole & Henderson, 2006a; H. Chen et al., 2019; W. J. Chen & Howe, 2017; Kershner & Hollingworth, 2023; Williams et al., 2005). Of course, evidence of poor explicit memory in studies using abstract stimuli may indicate that, under some circumstances, learning may be implicit and unconscious, but even this more limited conclusion is currently under substantial debate (Gimenez-Fernandez, Luque, Shanks, & Vadillo, in press; Giménez-Fernández et al., 2023; Meyen et al., in press; Shanks, Malejka, & Vadillo, 2021; Vicente-Conesa, Giménez-Fernández, Luque, & Vadillo, 2023). If we take real-world visual perception, attention, and memory as the ultimate domain of explanation (and we should), current evidence indicates that selection history effects are likely to driven by memory representations that are available for explicit retrieval and report. This does not mean that people will explicitly retrieve every real-world episode contributing to a learned bias, nor does it mean that explicit recall is required for the guidance of attention (as discussed above), but rather that the format of the memory representation generated by naturalistic stimuli is likely to be inherently explicit rather than implicit.

Category-specific Inter-trial Repetition

Finally, we observed a new form of inter-trial repetition effect in the present study: Location and color repetition advantages that were contingent on object category. Object categories are likely to play a central, structural role in attention guidance. Many real-world searches require finding any member of a target category, such as finding a member of the category ‘hammer’ when wishing to drive in a nail (Malcolm & Henderson, 2009; Vickery, King, & Jiang, 2005; Yang & Zelinsky, 2009). In previous work on categorical search, search templates have been shown to be biased toward typical features of that category (Maxfield, Stalder, & Zelinsky, 2014) and to influence the efficiency of attention guidance to the target, rather than post-selection processes (Bahle et al., 2021). Here we showed that the parameters of guidance when searching for a category member are influenced by properties of the last observed exemplar in that category (see also Bahle et al., 2021). That is, the target template was not limited to typical features but also reflected features observed in recent search episodes, indicating that templates are sensitive to recent, category-specific statistics. These effects were observed even though category repetitions were separated, on average, by 36 trials. Such delays suggest that target repetition effects in visual search reflect not just short-term priming (Maljkovic & Nakayama, 1994) but also the episodic influence of previous searches (Asgeirsson & Kristjansson, 2011; Huang, Holcombe, & Pashler, 2004; Thomson & Milliken, 2012, 2013) stored in long-term memory.

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Open Practices

The data and materials for the experiments reported here are available upon request.

None of the experiments was preregistered.

Figure Captions

Figure 1. Overview of method in Experiment 1. **A**. In the visual search task, participants saw a label describing the target category, followed by a search array. They searched for the object that matched the label and reported the orientation of a superimposed letter “F”. **B**. The set of target object stimuli for a sample category. Note that due to licensing restrictions, the object photographs in this figure differ slightly from those used in the experiments.

Figure 2. Experiment 1 results. **A**. Inter-trial analysis probing the repetition of search target location from trial N-1 to trial N. The data as a function of search epoch appear in **B**. **C**. Inter-block analysis probing category-specific repetition of target location and color. The data as a function of search epoch appear in **D**. Error bars are condition-specific, within-subject 95% confidence intervals (Morey, 2008).

Figure 3. Experiments 2-4 surprise memory test methods. For Experiments 2 and 3, immediately after responding to the 36th trial of search, participants completed a single-trial test in which they were asked to report either the location (**A**, Experiment 2A and 3A) or the color (**B**, Experiments 2B and 3B) of the last target object they found. In Experiment 4, after two blocks of search, participants completed 36 trials (one for each category), in which they reported either the location (**C**, Experiment 4A) or the color (**D**, Experiment 4B) of the target from that category the last time they found one.

Appendix

Table 1. The first column lists the 36 categories used in each experiment. The second two columns list the general exemplar colors used for each category. The last two columns list the hexadecimal color values used for the color patch alternatives in the surprise memory tests.

Target Category	Color 1	Color 2	Hex 1	Hex 2
Apple	Red	Green	#770314	#B1C633
Beans	Tan	Dark Red	#F2C78C	#9C2941
Bear	White	Brown	#DACEB8	#5E3E2A
Bell Pepper	Yellow	Green	#FCC906	#56843B
Butterfly	White	Orange	#EFECCF	#F77707
Cat	Grey	Tan	#847F7B	#BE8250
Rat	Black	White	#332C27	#D7D2CF
Beetle	Red	Black	#A9150E	#1E1E24
Dog	Brown	Black	#A57155	#1F1F1F
Frog	Red	Green	#F70E08	#AAD533
Grapes	Red	Green	#AD1422	#B9C724
Horse	Brown	Black	#714D28	#151514
Leaf	Red	Green	#BD090A	#6ABB36
Pear	Yellow	Green	#FBC042	#9CAC05
Mushroom	Red	Brown	#D72B29	#824522
Onions	White	Dark Red	#E3E4DC	#79212D
Rabbit	Tan	White	#CD9A73	#D8D7D4
Bird	Red	Brown	#DB4428	#CB9465
Backpack	Yellow	Black	#E0B248	#2F2D2E
Bed	Brown	Black	#C3895B	#393837
Camera	Black	Blue	#222121	#1358D0
Car	White	Red	#E5E5E7	#CC1212
Mug	Green	Grey	#A8B53E	#878986
Dress Shirt	Light Blue	Light Green	#B7D3E9	#C0DFC0
Dress	Yellow	Blue	#F3C441	#2034AB
Baseball Cap	Black	Brown	#242424	#BCB09E
Laptop	Red	Black	#EF3141	#444546
Chair	White	Brown	#DADADA	#A55F3E
Hair Brush	Red	Blue	#F52A24	#08AAF3
T-Shirt	Yellow	Red	#F9E525	#D72638
Tricycle	Blue	Yellow	#0672BE	#FAF472
Perfume Bottle	Pink	Purple	#F1D0C7	#6B2A70

Cooking Pot	Silver	Black	#D1D7DB	#353B46
Wristwatch	Silver	Gold	#B1B1B3	#E5C870
Running Shoe	Blue	Black	#435A7C	#232324
Stapler	Red	Green	#E33B55	#75EF7D

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