Reward-Driven and Memory-Driven Attentional Biases Automatically Modulate Rapid Choice

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Abstract

In two experiments we examined the influence of 'history-driven' attentional biases on choice behavior. In Experiment 1 we used a value-modulated attentional capture procedure to induce an automatic reward-related attentional bias, and found that this bias shaped choice in a subsequent task in which participants were required to pick the highest number from a briefly displayed choice array. In Experiment 2 we investigated the influence of a working memory manipulation, and found that choice in the number-selection task was influenced by the current (and prior) contents of memory, consistent with an influence of memory-driven attentional bias on information encoding. Our findings indicate that history-driven attentional biases can translate to an influence on overt, downstream processes of behavioral choice, and should be incorporated into models of the interaction between attention and choice.

Keywords: attention; choice; decision making; reward; memory

Introduction

Traditional studies of decision making involve presenting a tightly circumscribed set of options (press button A or button B; choose the most attractive of four faces). However, real-world decisions are less constrained. For example, in the supermarket we may face an array of thousands of potential options, and there is no way that we could feasibly weigh up the pros and cons of each before making a choice. Attention plays a critical role here by prioritizing some candidate items and deprioritizing others, dramatically narrowing the pool of options under consideration.

Contemporary models characterize the role of attention in choice within the sequential sampling framework (e.g., Busemeyer & Townsend, 1993; Cavanagh et al., 2014; Krajbich, 2019; Krajbich et al., 2010; Newell, 2005; Newell & Le Pelley, 2018; Sepulveda et al., 2020; Smith & Krajbich, 2019). These models specify a casual influence of attention on choice: the more attention an option receives, the more rapidly evidence accumulates in support of that option. On this view, to gain a full understanding of why we *choose* some options over others, we must understand why we *attend* to some options over others.

Clearly, goal-driven processes are an important determinant of attention (see Yantis, 2000) and will influence choice (Callaway et al., 2021; Sepulveda et al., 2020): if we have gone to the supermarket to buy milk, we will tend to prioritize the dairy section, and white items, and cartons etc. Likewise attention can be shaped by the physical salience of stimuli; that is, how distinctive items are relative to their surroundings (Theeuwes, 1992). Even if we are in the supermarket to buy milk, our attention may be captured by a brightly colored sign advertising that detergent is on sale, in turn increasing the likelihood that we choose to buy detergent (Towal et al., 2013; Vanunu et al., 2021).

More recent research suggests a further class of influences on attention that relate to our previous experience with stimuli, independently of our current goals and the physical features of those stimuli (Failing & Theeuwes, 2018; Theeuwes, 2019; Watson et al., 2019b). In the current study, we investigate whether two of these experience-related influences on attention—relating to reward learning and memory—can also modulate and bias decision-making behavior. This is a critical issue, because it is our choices that ultimately determine our interaction with the world.

Experiment 1: Reward-related attention and choice

Prior research has shown that stimuli associated with reward (e.g., money or tasty food) become more likely to capture our attention in a way that we have little control over, and can do little to resist (see Anderson, 2016; Le Pelley et al., 2016; Pearson et al., 2022; Rusz et al., 2020). Importantly for current purposes, recent findings are in line with the idea that this reward-related attentional bias can modulate choice behavior (Gluth et al., 2018, 2020). For example, Gluth et al. (2018) had participants complete a choice task in which they had to choose rapidly between stimuli that differed in their color and orientation, where these features determined Expected Value (EV): color signaled the associated reward magnitude, and orientation signaled the probability of receiving that reward if the option was chosen. On critical trials, three options appeared in the display, but 100 ms after stimulus onset, a pink frame appeared around one of the options signaling that if it was chosen, no reward could be earned. Notably, the EV associated with this unrewarded 'distractor' option nevertheless influenced participants' choice behavior: participants sometimes mistakenly chose the distractor, and critically were more likely to do so when it was associated with high EV versus low EV. The presence of a high-EV distractor (versus a low-EV distractor) also resulted in longer response times to correctly choose one of the 'available' items, suggesting that high-EV distractors

In M. Goldwater, F. K. Anggoro, B. K. Hayes, & D. C. Ong (Eds.), *Proceedings of the 45th Annual Conference of the Cognitive Science Society*.

were more likely to interfere with ongoing choice behavior. Analysis of gaze data indicated that these effects were mediated by overt attention towards the distractor option.

While Gluth et al.'s findings are in line with the idea that reward-related attention can bias subsequent choice, they have one major limitation, relating to the fact that the (supposedly) attention-biasing value of the 'distractor' option was defined during the choice task itself. When the three items were initially presented, all three appeared as valid options of choice, and all were associated with a particular EV. For example, participants may have experienced over many trials that choosing a horizontal green item often produced a large reward, rendering them more likely to choose horizontal green items in future. And critically, participants may have sometimes chosen this item even if it was subsequently (after 100 ms) revealed to be an unrewarded 'distractor' – if they could not inhibit this prepotent, learned response tendency. On this account, choice of (and attention to) the distractor may be a direct result of its associated value in the choice task (participants choose the distractor due to its prior association with high EV), rather than an indirect result of an attentional bias (participants attend to the distractor due to its prior association with high EV, which biases evidence accumulation towards the distractor, which in turn biases choice towards the distractor).

Stronger support for a biasing influence of reward-related attention on the process of choice would come from a design in which the source of the attentional bias is independent of the values of options in the choice task. This was the approach we used in Experiment 1. Specifically, we used a validated value-modulated attentional capture (VMAC) task to establish a counterproductive, reward-related attentional bias to colored stimuli, before deploying these stimuli in a subsequent (simple) choice task. Critically, colors had no significance to the choice task (color was unrelated to option-values in this task) so any influence of experience from the prior VMAC task on choice must reflect the effect of an existing attentional bias on decision making. The key question was whether reward-related attentional bias would influence performance in the choice task: whether participants would be more likely to choose items associated with higher reward-related attentional priority.

Method

Participants and Apparatus

Thirty-one UNSW Sydney students participated in Experiment 1 (20 female, 11 male; age $M = 19.1$, $SEM = 0.4$ years) for course credit, and also received a performance-related payment (M = 9.58 AUD, SEM = 0.20 AUD). Eye movements were tracked using a Tobii Pro Spectrum eye-tracker (600 Hz sample rate) mounted on a 23-inch monitor. During the search task, head positioned was stabilized with a chin rest 60 cm from the monitor. Stimulus presentation was controlled by MATLAB using Psychophysics Toolbox extensions (Kleiner et al., 2007). All code and data relating to experiments reported in this paper are available at https://osf.io/gcj7e/.

Stimuli and Design

VMAC task The VMAC task (Fig 1a) was based on a well-validated visual search procedure (Le Pelley et al., 2015; Pearson et al., 2015; Pearson & Le Pelley, 2020; Pearson et al., 2016; Pearson et al., 2020; Watson et al., 2019a; Watson et al., 2020). On each trial, participants had to look at a diamond-shaped target among circles to earn reward. One of the circles in the search array—termed the *distractor*—could be colored either blue or orange, and the color of the distractor signaled whether a high or low reward was available on that trial. However, participants never had to respond (or attend) to the distractor to earn the reward; indeed, looking at the distractor was counterproductive since it led to cancellation of the reward that could otherwise have been earned. The reliable finding is that participants are nevertheless more likely to look at a distractor that signals high versus low reward, suggesting an influence of reward history on attentional capture, independent of goals and physical salience. That is, the VMAC effect shows that the attentional priority of reward-signaling stimuli is increased such that people are often unable to prevent themselves from attending to such stimuli, even when doing so is maladaptive.

All stimuli appeared on a black background. Each trial began with a central, white fixation cross inside a small white circle. After 700 ms of gaze dwell time had accumulated inside the circle, the cross and circle turned yellow for 300 ms, followed by a 150-ms blank screen. The search array then appeared: five circles and one diamond, each subtending 2.3°×2.3° visual angle, spaced equally around screen center at 5.1° eccentricity. One of the circles could be either blue or orange; all other shapes were grey. The color of this distractor circle signaled whether high (500 points) or low (10 points) reward was available on the current trial: assignment of colors to reward values was counterbalanced across participants. Target and distractor locations were determined randomly on each trial.

A response was registered when 100 ms of gaze dwell time had accumulated on the diamond target. If any gaze was recorded on or near the distractor (within a region of 5.1°

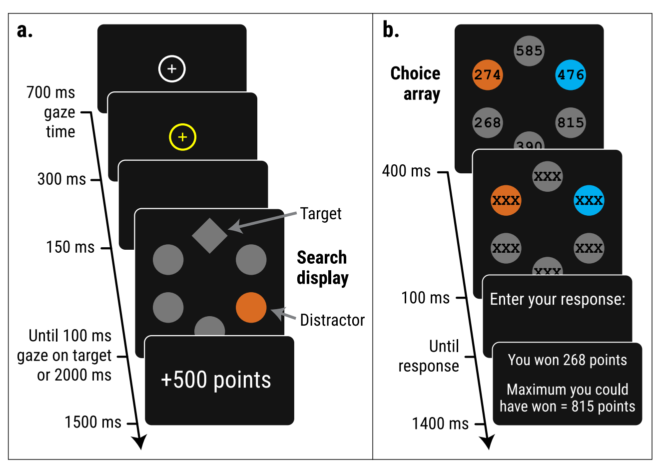

Fig 1. Schematic of (a) VMAC task and (b) choice task in Experiment 1; see text for details.

diameter centered on the distractor) prior to response, the reward on that trial was cancelled; these were termed *distraction trials*. If no response was recorded within 2000 ms, the trial timed out.

Immediately following response or timeout, feedback appeared for 1500 ms. If response time was below 1000 ms and it was not a distraction trial, feedback stated the number of points earned. If response time was below 1000 ms and it was a distraction trial, feedback stated "0 points – you could have won [500 / 10] points" as appropriate. If response time was above 1000 ms or the trial had timed out, feedback stated "Too slow", followed by the same message that appeared on distraction trials.

There were 60 trials in each block of the VMAC task: 26 trials with the high-reward distractor, 26 trials with the low-reward distractor, and 8 distractor-absent trials (in which all items in the search array were grey and 10 points were available), in random order.

Choice task We examined the influence of reward-related attention on rapid choice in a conceptually simple choice task. Each trial began with an 800-ms central fixation cross. The choice array then appeared, comprising six circles in the same locations as shapes had appeared in the VMAC task. On *single-distractor* trials, one of the circles was blue or orange; on *double-distractor* trials, the array contained both a blue and an orange circle (Fig 1b). All other circles were grey. Each circle contained a number in black text, drawn randomly from the range 0 to 999. After 400 ms the numbers inside the circles were masked with "XXX" for 100 ms. The choice array then disappeared, and participants were cued to enter a number. If the number had appeared in the choice array, they won that number of points; if the number had not been in the choice array, they won nothing. After entering their response, feedback (for 1400 ms) stated the number of points earned, and what the highest number in the array had been. The next trial began after a 1200-ms blank interval.

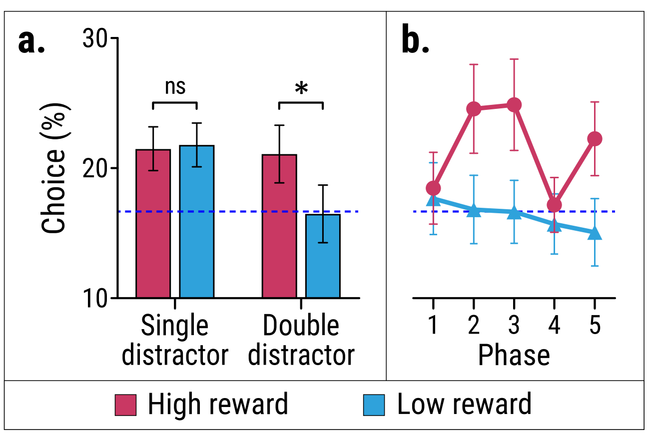

Fig 2. Proportion of valid choice responses (i.e., choices of a number that appeared in the choice array) in the choice task of Experiment 1. (a) Choice of the number appearing in the circle rendered in the high-reward color from the VMAC task vs the low-reward color, for trials with a single colored distractor in the choice array and double-distractor trials with both colors in the same array. (b) Data from double-distractor trials plotted across phases of the choice task. Error bars show *wSEM*; blue dotted line shows chance performance.

Each block of the choice task contained 40 trials: 10 single-distractor trials with the high-reward color from the VMAC task; 10 single-distractor trials with the low-reward color; 10 double-distractor trials; and 10 distractor-absent trials (all grey circles).

Procedure

Participants were initially given instructions for (and practiced) both tasks. For the VMAC task they were told they should look at the diamond as quickly and directly as possible, that the color of a circle in the display signaled the available reward (e.g., blue signals 10 points and orange signals 500 points), but that if they looked at the colored circle the reward would be canceled. For the choice task, participants were told they should try to report the highest number in the choice array, since this would allow them to earn the most points. To incentivize performance, participants were told the number of points that they earned would translate to a monetary bonus at the end of the study ("typically $8-$16"). They then alternated five times between phases of the VMAC task (two blocks) and the choice task (one block). Brief instructions prior to each phase summarized the aim of the upcoming task.

Results and Discussion

VMAC task

We first analyzed data from the VMAC task to verify the presence of a reward-related attentional bias. Following standard protocols (Pearson & Le Pelley, 2020; Pearson et al., 2020; Watson et al., 2021), we excluded data from the first two trials of each block, timeouts (1.7% of all trials), and trials with poor eye tracking (<25% valid gaze data: 0.1% of all trials). For remaining data, there was a greater proportion of distraction trials for search arrays with a high-reward distractor (M = 33.7%) than a low-reward distractor (M = 12.0%; within-subjects *SEM* [*wSEM*, Morey, 2008] = 2.6%), $t(30) = 8.46$, $p < .001$, $d_z = 1.5$. Thus, in line with previous research, the VMAC task created a reward-related attentional bias: participants were more likely to look at a distractor that signaled availability of high versus low reward, even though this behavior was counterproductive since it resulted in cancellation of more high- than low-value rewards. The implication is that the high-reward color came to receive automatic attentional priority, independent of (indeed contrary to) participants' goal to maximize their earnings.

Choice task

Most importantly, this reward-related attentional bias created a subsequent choice bias in the choice task. Fig 2 shows the proportion of trials on which participants reported the number contained in the colored circle during the choice task. For single-distractor trials, participants were not significantly more likely to report the number in a circle rendered in the high-reward color (from the VMAC task) versus the low-reward color, $t < 1$, with one-sample tests revealing above-chance (16.7%) choice of both options, both $t(30) \geq 2.41$, $p \leq .022$, $d_z \geq 0.43$. Critically, however, for double-distractor trials participants were significantly more likely to report the number in the high-reward-color circle than the low-reward-color circle, $t(30) = 2.08$, $p = .046$, $d_z = 0.37$,[1] with above-chance choice of the high-reward-color item, $t(30) = 2.66$, $p = .012$, $d_z = 0.37$, but not the low-reward-color item, $t < 1$. The difference in choice on double-distractor trials effect did not reflect a difference in the value of the choice option: the mean rank of chosen numbers in the high-reward circle ($M = 4.02$, where 6 represents the highest rank / largest number) was no greater than that for chosen numbers in the low-reward circle ($M = 4.03$), $t < 1$.

To summarize, when both reward-related colors appeared in the choice array, participants more often chose the number in the high-reward color than the low-reward color – even though color was irrelevant to this task, in that numbers were assigned randomly to locations. This finding indicates that automatic biases in reward-related attention can shape subsequent processes of information gathering and hence influence overt behavioral choice.

No difference in choice was observed between trials with a single distractor in the high- versus low-reward color. On these trials, the colored circle was the only physically salient item in the display (all other items were grey circles). Hence this colored circle may have captured attention based on its status as a color singleton (Theeuwes, 1992), regardless of its associated reward value, resulting in encoding of the number it contained. By contrast, when both reward-related distractors appear in the same display (with both having similar physical salience), the competition between the two will be resolved by differences in reward-related priority – resulting in a difference in encoding.

We postpone further discussion of these findings for the moment, and turn to Experiment 2 in which we investigated an alternative source of attentional bias in relation to subsequent choice.

Experiment 2: Memory-driven attention and choice

Automatic attentional biases arise not only as a function of prior learning about rewarding events. Research shows that the contents of working memory can act as an attentional template, increasing the priority of perceptually similar inputs (e.g., Hollingworth & Luck, 2009; Olivers et al., 2006; Soto et al., 2005; Sun et al., 2015). For example, Sun et al. (2015) used a memory task in which participants had to remember a colored circle (study item). In the retention interval between seeing the study item and being asked to recall it, participants performed a search task in which they had to locate a target shape. Even though color was irrelevant to this task, responses to the target were slower when the display contained a distractor in a color that matched the contents of working memory versus an equally salient but non-memorized color. Such findings show that the contents of memory can modulate attentional priority.

As for reward, existing research in this area has focused on effects on attention, rather than examining how such biases shape downstream decision making. The demonstration of an influence of memory-driven attentional bias on subsequent choice would show that information need not be currently present to influence a decision; that choice can be systematically biased by information held in memory, rather than in the environment. This issue formed the basis of Experiment 2, in which we combined Sun et al.'s procedure for inducing memory-driven attention with the choice task of Experiment 1.

Participants and Apparatus

Experiment 2 was run online; 28 participants were recruited via Prolific (22 female, 6 male; age $M = 34.6$, $SEM = 2.0$ years) in exchange for 6 GBP, with the top-scoring 25% receiving an additional bonus of 2 GBP. Stimulus presentation was controlled by jsPsych (de Leeuw, 2015).

Stimuli and Design

Each trial in the main phase of the experiment began with a 500-ms fixation cross, before a colored circle (blue, green, or red; 50 px radius)—the *memory target*—appeared for 800 ms (Fig 3a). Following a 150-ms blank screen, the choice array appeared. This was similar to that in Experiment 1 (Fig 1b), with some changes: (1) Numbers in each circle were sampled randomly from a range from 100 to a randomly chosen upper limit of 600, 700, 800, 900 or 999; (2) The choice array appeared for 500 ms (vs 400 ms in Experiment 1); (3) Circles were 60-px radius, at an eccentricity of 240 px; (4) The whole choice array was rotated about screen center by a random angle from 0 to 60° on each trial (unlike in Experiment 1, where the top item was always directly above screen center); (5) The number in each circle appeared on a light grey background to increase legibility; (6) The choice array always contained two colored circles (blue, green, or red) in random locations; all other items were grey.

The choice array was then masked and participants entered their number response as in Experiment 1. Next, a *memory test* item—a single circle (blue, green, or red)—appeared and participants were cued to press S if it was the same as the memory target item they had seen earlier, or D if it was different. Feedback was then provided: participants were told how many points they had won in the choice task and what the highest number in the display had been, and whether their memory response was correct or incorrect. After 1500 ms participants could press any key for the next trial.

Each block contained 18 trials: each combination of 3 possible colors for the memory target, 3 possible combinations of pairs of colors in the choice array, and 2 possible correct responses for the memory task (same or different; if the correct response was different, the color of the memory test item was chosen randomly from the two non-target colors), in random order.

Procedure

Instructions first introduced the choice task, and explicitly noted that the colors of circles were irrelevant to this task, and

[1] Analysis excluding the first of the five cycles of VMAC-then-choice task (when participants may not have yet developed a strong reward-related attentional bias) revealed a somewhat more pronounced choice bias, $t(30) = 2.30$, $p = .029$, $d_z = 0.41$; see Fig 2b.

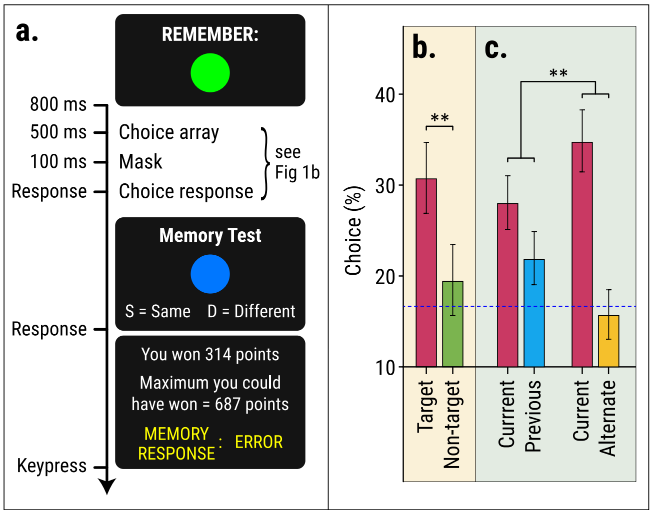

Fig 3. (a) Schematic design of Experiment 2. (b) Proportion of valid choice responses of the number appearing in the current memory target color vs other, non-target colors. (c) Left bars show data from choice arrays with the current memory target and the target from the previous trial; right bars show choice arrays with the current memory target and the third (alternate) color. Bars show mean proportion of choices of the number in the corresponding circle. Error bars show *wSEM*; blue dotted line shows chance performance.

that participants should try to ignore the colors and search for the highest number. To provide motivation, participants were told they could unlock medals (bronze, silver, gold, platinum, diamond, elite) by earning points – we omit details of how medals were earned, but all participants reached the elite medal by the end of the task. They were also informed that the top-scoring 25% of people would receive a bonus of 2 GBP. Participants were required to correctly answer check questions to ensure they understood these instructions before proceeding to practice the choice task in isolation.

Instructions then introduced the memory task, and stated that “Depending on how accurately you perform in the memory task, you will receive extra points at the end of the study – so you should try to make as many correct responses as possible, since this means you will be more likely to earn a bonus”. Instructions also emphasized that, while the colors were important for the memory task, they remained irrelevant for the choice task. The main phase of the task then began, comprising 8 blocks with a self-paced break between blocks during which participants were told how many points they had earned in the previous block, and an animation presented any medals unlocked since the previous break.

Results and Discussion

Accuracy on the memory task was high ($M = 94.6\%$, $SEM = 1.0\%$). Of more interest are data from the choice task. We excluded data from the first trial of each block. Across the subset of remaining trials in which the memory target appeared in the choice array, participants were significantly more likely to report the number contained in the memory target color than in the non-target color, $t(27) = 2.88$, $p = .008$, $d_z = 0.54$ (Fig 3b). That is, participants’ choices were biased towards the item in the choice array that matched the color of the target they were currently holding in memory.

Whether this influence of memory on choice reflects an automatic bias is debatable, however. Participants knew that performance in the memory task contributed to their chances of receiving a bonus payment. Consequently, they may have chosen strategically to attend to the current-memory-target color in the choice array as a way of ‘rehearsing’ that color prior to the memory test – and since number-locations were independent of color-locations in the search task, this target-colored item was as likely to contain the highest number as was any other location.

To investigate this issue further, we analyzed performance on the current trial as a function of the color of the memory target on the *previous* trial. If the requirement to hold a color in memory creates an automatic attentional bias (promoting subsequent encoding of items sharing that color) then that bias may persist for a time, and may continue to influence performance on the following trial. By contrast, if participants were strategically attending to items in the color of the current memory target (to enhance memory on the current trial), there would be no reason to continue to attend to this color on the subsequent trial since doing so would typically interfere with memory for the new target.

Hence we considered the subset of trials in which the color of the current target was different from the color of the target on the previous trial, and compared choice performance on trials where the choice array contained (1) the current memory target vs the previous memory target, versus (2) the current memory target vs the third color (that was not the target on the current or previous trial; we term this the *alternate*). Fig 3c shows the proportion of choices of the number contained in each option. ANOVA with factors of choice type (current–previous vs current–alternate) and chosen item (chose current target vs chose current non-target) revealed a main effect of chosen item, $F(1,27) = 9.86$, $p = .004$, $\eta^2_p = .27$, with participants more likely to report the item in the current memory target color than the non-target color (as in the overall analysis reported above). The main effect of choice type was nonsignificant, $F < 1$. Critically, there was a significant interaction, $F(1,27) = 15.6$, $p < .001$, $\eta^2_p = .37$: the bias towards the current memory target was smaller when the other item in the choice array had the color of the previous target than when it had the alternate (third) color. The implication is that the previous memory target color produced greater competition for attention (and hence was more likely to result in encoding of the choice item at its location) than was the alternate. This in turn implies that the choice bias reflected the operation of an automatic process, and was not a consequence of a strategy intended to improve memory of the current target.

General Discussion

Contemporary models of the role of attention in choice tend to focus on the ways in which differences in attention shape the process of evidence accumulation, but often neglect the question of how those differences in attention arise in the first instance. In two experiments, we investigated the influence of automatic, history-driven attentional biases—relating to experience of reward and memory—on rapid choice in a simple number-selection task.

In Experiment 1 we used a previously validated value-modulated attentional capture task to establish an automatic, reward-related bias to colors that signaled availability of high reward versus low reward. Critically, we found that this attentional bias persisted and transferred to influence behavior in a subsequent choice task, in which colors were irrelevant: participants were more likely to report numbers superimposed on the high-reward color versus the low-reward color. These findings extend prior work by Gluth et al. (2018, 2020) to a situation in which the attention-biasing aspect of the distractor item in the choice task (here its color) is independent of its value in the choice task. This is important because (as noted in the Introduction) it creates conditions under which the choice bias can be more confidently ascribed to attention: participants attend to the distractor because it has previously been associated with high value, which biases encoding of the distractor, which in turn biases choice towards the distractor.

In Experiment 2 we examined an alternative memory-driven attentional bias, based on previous work demonstrating that items matching the contents of visual working memory are more likely to receive automatic attentional priority (e.g., Hollingworth & Luck, 2009; Olivers et al., 2006; Soto et al., 2005; Sun et al., 2015). Once again we found that this memory-driven bias translated into an influence on choice in our number-selection task. A particularly compelling finding was that choice was not only influenced by the current memory target, but also by the (now-irrelevant) target from the previous trial, indicating that the choice bias did not reflect a controlled, memory-enhancing strategy ('focus on the target color'). Instead these findings are more consistent with the idea that items held in visual working memory exert an automatic and lingering bias on attentional selection.

As noted earlier, prior research has shown that top-down attentional biases driven by goals, and bottom-up biases driven by physical salience can shape choice. Our findings suggest that history-driven attentional biases—which lie outside this traditional dichotomy (Awh et al., 2012; Theeuwes, 2019)—can also modulate choice. Hence this study provides an existence proof that history-driven biases can translate to an influence on overt, downstream processes of behavioral choice. This is a crucial issue, because it is our overt behavior that determines our interaction with the world around us; consequently, establishing how such biases shape ongoing behavior is vital to understanding the role of attention as a central component of cognition. This is particularly notable in the context of studies suggesting a link between reward-modulated attention and cognitive processes in addiction and compulsion (e.g. Albertella et al., 2019a, 2019b, 2020; Anderson et al., 2013).

Our experiments clearly have some limitations. First, distractor color was independent of choice value in both experiments: while there was no advantage in attending to reward/memory-related colors, there was also no disadvantage to doing so. A more powerful demonstration would use a procedure in which participants know that the largest number will *never* appear in a colored circle, creating a goal of avoiding colors. If participants nevertheless remain most likely to choose the item in the reward/memory-related color, this would constitute a pattern of suboptimal choice created by an attentional bias.

Second, since Experiment 2 was run online, we could not use eye-tracking to confirm the presence of an attentional bias (as we did in Experiment 1) created by the memory manipulation. Given substantial prior evidence it seems highly likely that the effect on choice was mediated by attention, but this remains for future research to confirm.

The third, and most important, limitation relates to the choice task itself. Whereas the number-selection task is a good starting point— providing a simple test of the influence of attentional bias on choice— it is also a very limited test. The task of picking the highest of a set of numbers is clearly at the lower end of what we would consider a 'decision'. Moreover, any attention-driven decision bias that we observe in such a task must surely be short-lived: if we were to show the choice array for (say) five seconds, we can be confident that participants would pick the highest possible number on each trial – and hence show no bias (cf. Gluth et al., 2018, who also found no reward-driven attentional bias for slower choices). It seems highly likely that the bias observed in the current experiments relates to information encoding: participants have insufficient time to encode all items in the choice array, and hence their responses will be skewed towards the items that they encode first – which in turn will be the items they attend to first.

This issue arises because there is a clear-cut 'correct' choice in the number-selection task—the highest number—and so given enough time, goal-directed behaviour will always end up at this option. Future research could examine other choice tasks in which there is not a clear-cut correct response (e.g., risky choice) to probe the possibility of a longer-duration influence of attentional bias on choice, wherein attention modulates the dynamic, ongoing process of evidence accumulation rather than merely the initial encoding of information from which evidence accumulation proceeds.

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