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Reward-associated stimuli capture the eyes in spite of strategic attentional set

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ABSTRACT

Theories of reinforcement learning have proposed that the association of reward to visual stimuli may cause these objects to become fundamentally salient and thus attention-drawing. A number of recent studies have investigated the oculomotor correlates of this reward-priming effect, but there is some ambiguity in this literature regarding the involvement of top-down attentional set. Existing paradigms tend to create a situation where participants are actively looking for a reward-associated stimulus before subsequently showing that this selective bias sustains when it no longer has strategic purpose. This perseveration of attentional set is potentially different in nature than the direct impact of reward proposed by theory. Here we investigate the effect of reward on saccadic selection in a paradigm where strategic attentional set is decoupled from the effect of reward. We find that during search for a uniquely oriented target, the receipt of reward following selection of a target characterized by an irrelevant unique color causes subsequent stimuli characterized by this color to be preferentially selected. Importantly, this occurs regardless of whether the color characterizes the target or distractor. Other analyses demonstrate that only features associated with correct selection of the target prime the target representation, and that the magnitude of this effect can be predicted by variability in saccadic indices of feedback processing. These results add to a growing literature demonstrating that reward guides visual selection, often in spite of our strategic efforts otherwise.

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1. Introduction

Humans and other animals tend to approach environmental objects that have proven beneficial in prior experience and stay away from objects that have not. This approach bias is thought to begin as early as during sensation and perception, with neurochemical signals of reward having a unique ability to induce low-level visual plasticity that causes reward-associated stimuli to become salient and attention-drawing (Berridge & Robinson, 1998; Hickey, Chelazzi, & Theeuwes, 2010a; Roelfsema, van Ooyen, & Watanabe, 2010). Such a bias might have the evolutionary utility of increasing the likelihood that we notice potentially-rewarding objects in our environment.

A number of recent studies have investigated the oculomotor correlates of this reward-priming of selection in humans. Most of this work has relied on variations of a training paradigm established in studies of covert, non-saccadic selection: participants initially learn an association between a stimulus and reward before subsequently completing a test where (a) reward is no longer

awarded, and (b) the formerly-reward-associated stimulus can appear as a nontarget (see Anderson, Laurent, & Yantis, 2011a, 2011b). For example, Anderson and Yantis (2012) had participants train in a visual search task where one of two target colors was associated with a greater probability of high-magnitude reward. At test participants searched for a uniquely-shaped target presented among distractors of varying color. Results showed that the eyes were more likely to be misdirected into the visual hemifield that contained a distractor characterized by the formerly-reward-associated color. This occurred in spite of the fact that no reward was awarded during test and participants knew that color was no longer task relevant (see also Theeuwes & Belopolsky, 2012).

This kind of result is consistent with the idea that reward feedback has a low-level impact on visual representations, causing reward-associated stimuli to become visually salient. However, it is not clear whether the impact of reward identified in training studies necessarily reflects the direct, unique impact of reward on vision proposed by theory, or the influence of mediating cognitive mechanisms like selective attention. For example, imagine that during training participants become explicitly aware of the relationship between stimuli features and reward outcome. This would likely cause them to establish an endogenous attentional

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set for these high-value stimuli. Such a set is known to have residual effects in visual search even when task confines change (e.g. Leber, Kawahara, & Gabari, 2009; Tseng, Gobell, & Sperling, 2004), and could possibly be of greater-than-normal strength, given that it is repeatedly reinforced during training. Subsequent bias towards reward-associated stimuli could reflect this attentional set rather than any direct impact of reward on vision; this attentional set happens to be motivated by the reward, but it is not a direct, unique product of such. Similarly, even if participants are not explicitly aware of the relationship between stimuli and outcome they may very well have implicit knowledge of these statistical regularities, and this kind of implicit knowledge of statistical regularity is known to guide spatial attention (e.g. Chun, 2000; Chun & Jiang, 1998; Turk-Browne, Jungé, & Scholl, 2005). Results demonstrating change in the processing of reward-predictive stimuli when participants have no explicit awareness of this relationship thus remain a potential product of the use of implicit knowledge to prepare attentional set (e.g. Kristjánsson, Sigurjónsdóttir, & Driver, 2010).

In an effort to control for this problem of interpretation some studies of covert visual search have employed paradigms that do not tie reward to specific stimuli features. For example, in Hickey, Chelazzi, and Theeuwes (2010a) participants were randomly rewarded for correctly completing a visual search task involving selection of a shape singleton. This target was presented among a number of distractors, most of them identical to one another and of the same color as the target, but one of them singled out by unique color. This color singleton distractor was red while all other stimuli were green or vice versa, and this changed randomly from trial to trial. The colors defining the target and distractor could thus be the same as in the previous trial or could swap.

This design has two critical features: first, because search was always for the unique shape, color was entirely task-irrelevant. Second, though participants were paid based on the reward feedback provided on a trial-by-trial basis, reward was actually random and participants were equally likely to receive high-magnitude or low-magnitude reward after any correctly completed trial. As such, there was no opportunity for participants to explicitly or implicitly learn about a relationship between stimuli and reward. In spite of this, behavioral and event-related-potential results show that participants were more likely to attend to the distractor when it had the color that had characterized the high-reward target in the immediately preceding trial (see also Della Libera & Chelazzi, 2009; Hickey, Chelazzi, & Theeuwes, 2010b, 2011). This pattern sustained even when the experimental paradigm was modified such that high-magnitude reward on one trial was predictive of a change in target color in the next, making it strategically counter-productive to search for the reward-associated stimulus (Hickey, Chelazzi, & Theeuwes, 2010a, E1).

We have recently demonstrated that this non-strategic effect of reward can be indexed in eye movements, and particularly in saccadic curvature (Hickey & van Zoest, 2012). Participants in this study moved their eyes from a central fixation point to a red or green target that could be located at the top or bottom of the display. In every trial a distractor appeared to the left or right of the straight-line path to the target; this distractor could be red, with the target green, or vice versa. Stimuli colors were randomly determined for each trial, but the target was always defined by its position and color was task irrelevant. Participants randomly received high- or low-magnitude reward feedback after each trial and we analyzed results as a function of (a) whether the trial immediately preceding the current trial had garnered high or low reward, and (b) whether the colors had stayed the same between trials or swapped. Results showed that during fast target-directed eye movements, saccades deviated toward the distractor when high-magnitude reward had been received and the colors had swapped

(such that the distractor acquired the color of the target from the preceding trial). In contrast, slow target-directed eye movements deviated further away. Reward thus appeared to increase distractor salience, eventually resulting in stronger distractor suppression, and this occurred under circumstances where there was no statistical regularity in the relationship between stimuli and reward that could be leveraged to create attentional set.

The paradigm adopted in Hickey and van Zoest (2012) was not explicitly designed to induce saccadic capture to the distractor location. However, analysis did reveal a reliable difference in capture rates: when the distractor was characterized by a reward-associated color participants were slightly more likely to misallocate their eyes to its location (3.6% vs. 2.5% of total trials). Here we further investigate the nature of this non-strategic, reward-elicited oculomotor capture effect. In order to elicit higher rates of capture in the current study we adapted an experimental paradigm extensively employed in existing studies of oculomotor capture (e.g. van Zoest & Donk, 2005; van Zoest, Donk, & Theeuwes, 2004). Participants searched for a uniquely-oriented horizontal line element presented in a large array of non-targets. Most of these nontargets were homogeneous but one differed from the others in orientation, rendering it a singleton distractor (see Fig. 1). We manipulated two critical parameters from trial to trial. First, in each trial either the target or distractor was uniquely red in color. Importantly, the red color was task irrelevant: it randomly characterized either the target or distractor in each trial with equal probability. Second, participants received either high-magnitude or low-magnitude reward after saccadic selection of the target. Participants were instructed to maximize reward and were paid based on the value accumulated throughout the experiment, but reward magnitude was actually randomly determined for each correctly-performed trial.

We approached this design with the idea that receipt of reward after saccadic selection of the salient target would cause the reinforcement of the target representation, rendering subsequent stimuli with the same unique color visually salient. As such, when successful selection of a red target resulted in reward, target selection in the next trial should be facilitated when the target is again characterized by red color. In contrast, if the red color comes to characterize the distractor this should increase the likelihood that the eyes will be misallocated to this stimulus.

In addition to this central hypothesis, we approached the data with a further question regarding the role of the quality of target selection in reward-priming. Given that we measure overt saccadic behavior we can analyze the current trial as a function of whether oculomotor capture occurred in the preceding trial. This allows us to answer a question that cannot be addressed in studies of covert selection: when participants select the distractor, causing the need for reorientation of the eyes to the target, does subsequent reward have an impact on target and distractor representations? Is reward-priming contingent on efficient target selection?

Finally, we were interested in the degree to which saccadic indices of the depth of feedback processing could predict subsequent eye movement behavior. Do subjects who spend more time processing feedback – who show longer saccadic dwell times on the target and feedback stimuli at the end of a trial – show subsequent differences in saccadic selection?

2. Material and methods

2.1. Participants

Seventeen observers ranged in age from 19 to 26 (average 23.6). All reported having normal or corrected-to-normal vision.
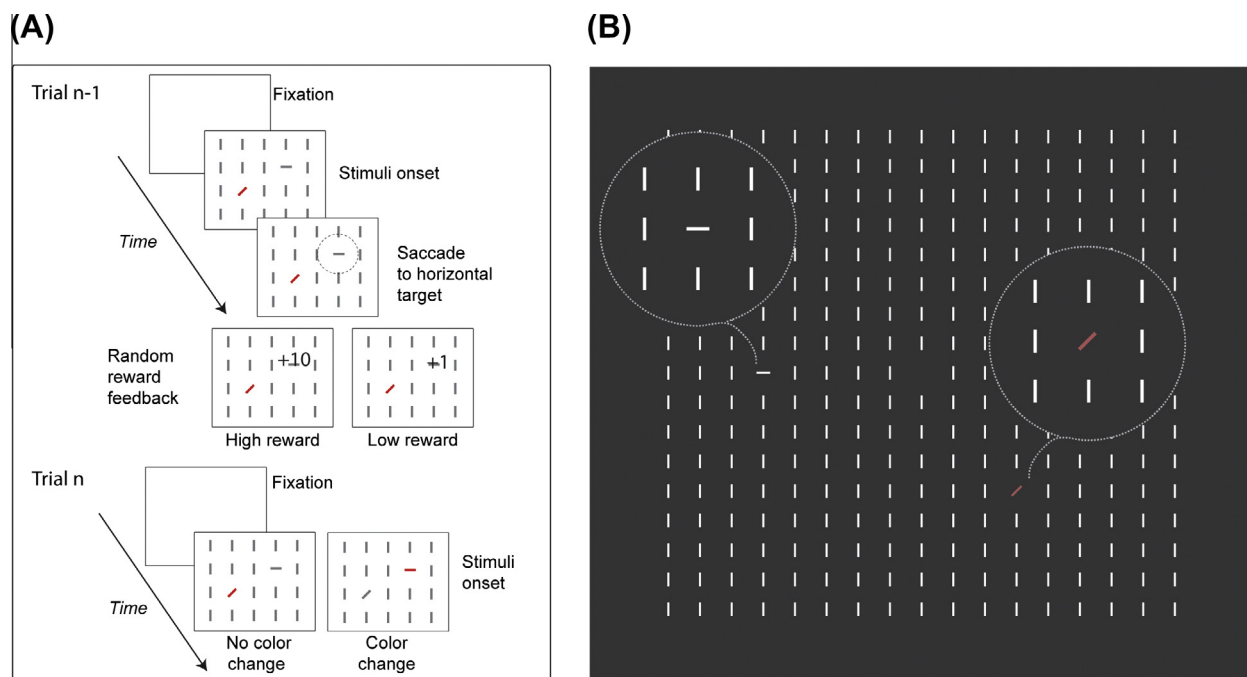
Fig. 1. General paradigm; correct target selection was awarded with 10 or 1 points (A). An example of the actual search display. The target was the unique horizontal line element. Target and distractor are magnified for the purposes of illustration (B).

2.2. Apparatus

All subjects were tested in a sound-attenuated, dimly-lit room with their heads resting on a chinrest. The monitor was located at eye level 75 cm from the chinrest. A Pentium IV computer with a processor speed of 2.3 GHz controlled the timing of the events. Displays were presented on an Iiyama 21″ SVGA monitor with a resolution of 1024 × 768 pixels and a 100-Hz refresh rate. Eye movements were recorded via an Eyelink II tracker (SR Research Ltd., Canada) with 500 Hz temporal resolution and a 0.2° of visual angle spatial resolution. The system uses an infrared video-based tracking technology to compute the pupil center and pupil size of both eyes.

2.3. Stimuli

The stimulus display consisted of multiple vertical line segments presented in a 17 × 17 square matrix with a raster width of 17.4° × 17.4° of visual angle (see Fig. 1). Each line element had an approximate length of 0.76° and width of 0.15°. The vast majority of elements were identical vertical white lines (RGB 200, 200, 200), but two unique singletons were present in each trial. One of these – the target – was a horizontal line. The other – the salient orientation distractor – was oriented either 45° to the left or 45° to the right. The two singletons could be presented at one of the six pre-defined locations in the display of equal retinal eccentricity (5.3° visual angle) with the sole confine that the target and salient distractor were always presented at opposite locations. In each trial either the target or distractor had unsaturated red color (RGB 200, 100, 100). Thus, in any given trial, either the target or the distractor was a red color singleton. All elements were presented on a gray background.

Reward feedback was provided to observers for 2500 ms immediately after successful selection of the horizontal target. Importantly, reward was provided regardless of whether the target or distractor was initially selected, so long as the eyes reached the target within 600 ms of saccadic onset. This meant that reward could be received in trials where the eyes were first de-

ployed to the distractor before being redeployed to the target. Feedback was presented in gray font (times new roman, 46.5 font; 1.5° visual angle height) at the target location and was either "+10", denoting the receipt of 10 points or "+1", denoting the receipt of 1 point. The visual search display remained onscreen during the presentation of the feedback. Trials in which the saccadic onset latency was shorter than 80 ms (anticipation errors), longer than 600 ms, or in which neither the target or distractor were fixated within the available time-period were considered errors. In these trials the display was removed from the screen and "−10" was presented at the center of the screen for 600 ms, denoting the loss of 10 points.

2.4. Procedure and design

Each block started with a nine-point grid calibration procedure. At the initiation of each trial drift-correction was performed such that center was established as the point of fixation. Participants initiated each trial by pressing the space bar, following which a fixation point was presented for a random duration of 300–600 ms before onset of the search display.

The experiment consisted of a practice session of 32 trials and an experimental session of 576 trials. The experimental session was divided into three blocks of 192 trials. Each observer contributed 144 trials in each of the 4 conditions resulting from the factorial combination of *prior reward* (high- vs. low-magnitude reward) and *color singleton identity* (target red vs. distractor red). Feedback regarding average saccadic latency and the total amount of reward collected in points and euros was provided after every 32 trials. Each point awarded during participation had a value of 0.285 euro cents, and on average participants received ∼8 euros for participation. Participants were instructed to initiate saccades quickly upon the appearance of the search display.

2.5. Data analysis

Default settings on the eye tracker were adopted for the detection of saccades: an eye movement was considered a saccade when

eye velocity exceeded 35°/s or eye acceleration exceeded 9500°/s², and end points were defined as the point when velocity fell below this threshold. Saccade latency was defined as the interval between the presentation of the saccade target and the initiation of a saccadic eye movement. If the eyes were not within 3° of the fixation point when the saccade was elicited the saccade was classified as an error and not further analyzed. The initial saccade was characterized as target or distractor directed if the endpoint was within 3° of the target or distractor position. Initial saccades that missed either the location of the target or the distractor counted as errors and were not analyzed further.

3. Results

Data from two participants were removed because performance was almost entirely determined by stimuli color (suggesting a misunderstanding of task instructions). In one case the participant was 91.5% likely to initially move the eyes to a red target but only 14.2% likely to select a white target. The other was 96.1% likely to select a white target but only 32.6% likely to select a red target. The color bias in these subjects was substantially larger than that observed in the remaining subjects (where the eyes were directed to a white and red target with 69.2% [15.7% SD] and 62.4% [13.9% SD] accuracy, respectively).

In the remaining 15 participants 0.11% of trials were discarded because saccade onset latency was shorter than 80 ms and 0.76% of trials were discarded because it was longer than 600 ms. A further 3.07% of trials were discarded because of inaccurate fixation at display onset and 6.91% were discarded because the saccade in either the current or preceding trial had landed on neither target nor distractor.

In 66% of remaining trials the initial saccade was correctly directed towards the horizontal target. Mean saccadic reaction time (SRT) in these trials was 240 ms. In the other 34% of these trials the initial saccade was to the distractor and mean SRT was 220 ms. This difference in SRT was significant, $t(14) = 4.30$, $p < 0.001$.

In our primary analysis the proportion of trials where the first eye movement was directed to the target was computed for each subject as a function of four factors: the identity of the stimulus initially selected in the preceding trial (*prior selection:* target vs. distractor), the color of the stimulus selected in the preceding trial (*prior selection color:* red vs. white), reward magnitude in the previous trial (*prior reward:* high vs. low), and whether the red color continued to characterize the same stimulus in the current trial as was the case in the preceding trial (*color identity change:* change vs. no change). These results are illustrated in Fig. 2.

Statistical analysis began with a repeated measures analysis of variance (RANOVA) based on the results illustrated in Fig. 2 with the factors described above. This revealed a critical four-way interaction, $F(1,14) = 8.39$, $p = 0.012$, which is further examined in follow-up tests below. A marginally significant three-way interaction between *prior selection*, *prior selection color*, and *color identity change* was also detected, $F(1,14) = 4.560$, $p = 0.051$, reflecting increased likelihood of the misallocation of the eyes to the distractor when (a) the target acquires red color immediately after a trial where the eyes were misallocated to a red distractor (Fig. 2B), and (b) the target acquires red color after a trial where the eyes were correctly allocated to a white target (Fig. 2C). This pattern describes a difficulty in selecting the target when the target has the salient color that has recently characterized a to-be-ignored distractor, regardless of prior reward outcome. An additional main effect of *color identity change* was detected, $F(1,14) = 68.88$, $p < 0.001$, reflecting increased likelihood that the eyes would be directly deployed to the target when the red color characterized the same stimulus in the current trial as it had in the preceding trial

(72% vs. 59%), alongside a marginally significant main effect of *prior reward*, $F(1,14) = 4.36$, $p = 0.056$, reflecting better performance following high reward (67% vs. 64%).

To gain further perspective on the critical four-way interaction we conducted follow-up RANOVAs limited to trials where selection in the preceding trial had been of either the red or white stimulus (i.e. with *prior selection color* held static). When the red stimulus was selected in the previous trial a significant three-way interaction between *prior selection*, *prior reward*, and *color identity change* was observed, $F(1,14) = 5.51$, $p = 0.034$. This effect is visually apparent in the difference in results between Fig. 2A and B: there appears to be an interaction between the *color identity change* and *prior reward* factors in Fig. 2A that is absent in Fig. 2B. No corresponding three-way interaction was observed when the white stimulus was selected in the preceding trial (cf. Fig. 2C and D), $F(1,14) = 1.17$, $p = 0.298$.

To parse this three-way interaction, a subsequent RANOVA with factors for *change* and *prior reward* was conducted based on results observed when the eyes had been efficiently deployed to a red target in the preceding trial (Fig. 2A). This revealed a reliable two-way interaction, $F(1,14) = 6.95$, $p = 0.019$. No interaction was observed when analysis was limited to trials where it was the red distractor that had been selected in the preceding trial (Fig. 2B), $F(1,14) = 1.17$, $p = 0.30$.

Analysis of accuracy results thus revealed that the eyes were more often deployed to a red stimulus, regardless of task relevance, following trials where selection of a red target garnered reward. To determine if saccadic response time in any way played a role in creating this pattern we conducted an additional omnibus RANOVA of saccadic response times with the same factors that were applied to the proportional results. This revealed only one significant effect: a three-way interaction between *prior selection, prior selection color,* and *color identity change*, $F(1,14) = 8.36$, $p = 0.012$. This interaction is driven by a speeded response when participants misallocated the eyes to a white distractor in the previous trial, causing the need for a corrective redeployment of attention to the red target, and the target in the current trial is red. This may reflect the establishment of cognitive control following a rather severe saccadic error: having misallocated the eyes to a relatively low-salience distractor, participants established strong set for the target and this benefits performance in the next trial when the target matches this set. In any case, this effect was not reliably sensitive to reward feedback, as reflected in a non-significant four-way interaction ($F < 1$). The accuracy results described above were thus not reliably sensitive to the speed of saccadic response.

Finally, we analyzed results from the critical condition illustrated in Fig. 2A as a function of the time that the eyes fixated on feedback in the preceding trial. Because the trial eventually ended there was an upper limit on the total time that the eyes could remain on the feedback. However, participants tended to break fixation early in order to return the eyes to the center of the screen, resulting in substantial between-subject variability in the total time that the eyes remained on the feedback. We calculated the average time that the eyes remained on feedback for each subject separately as a function of the magnitude of the feedback, and subsequently calculated a difference score by subtracting the time spent on low-magnitude reward from the time spent on high-magnitude reward. These values are plotted on the *x*-axis in Fig. 3A and B.

In a separate procedure we calculated for each of the reward conditions the difference in proportion-to-target results as a function of whether the identity of the red colored stimulus had changed between trials. This corresponds to a subtraction between the square and circle markers in Fig. 2A for each reward condition separately, and garners a numeric index of the impact of low-magnitude and high-magnitude reward on the strength of the
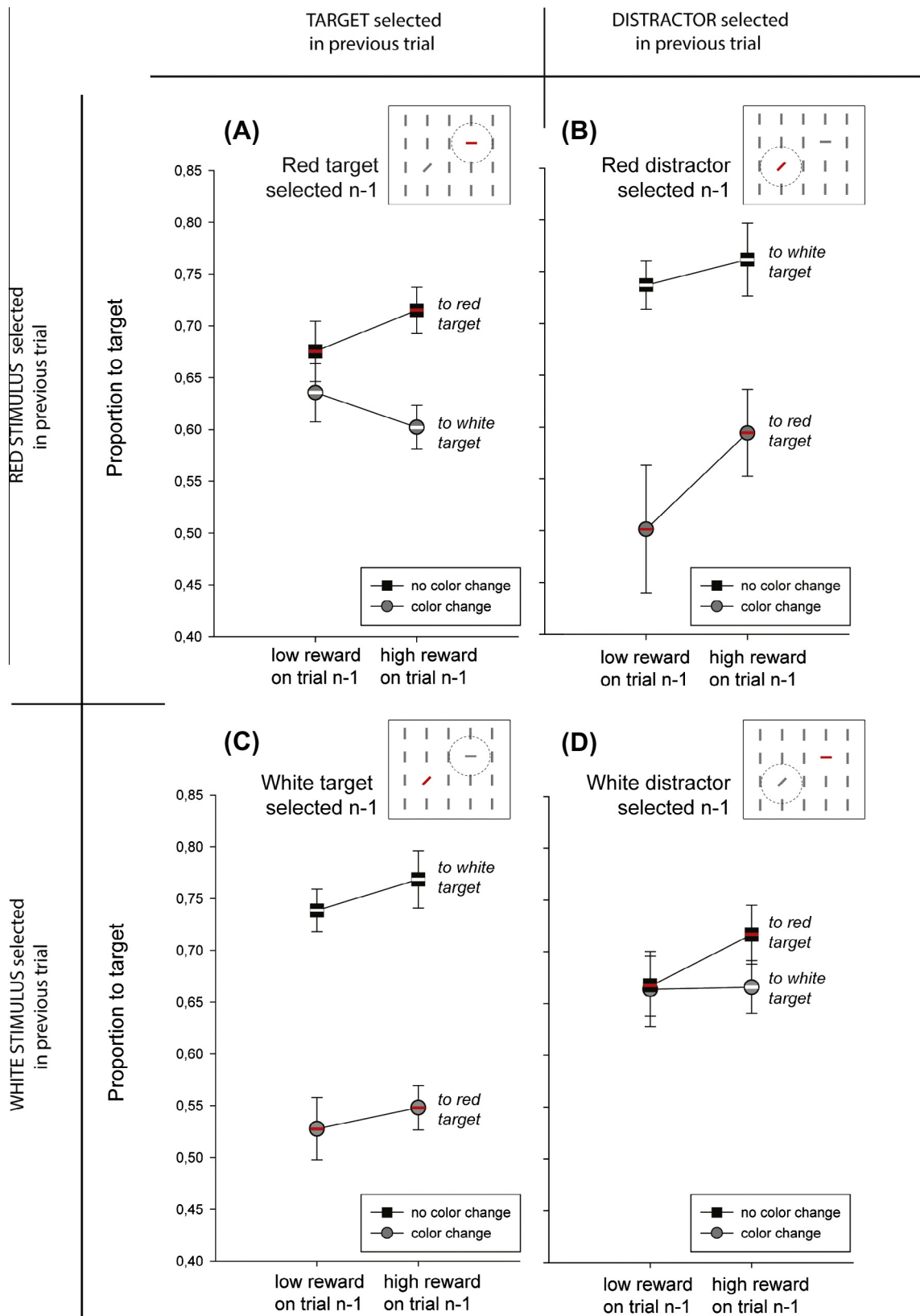
Fig. 2. The impact of prior reward and color swap on oculomotor performance when in the previous trial the target was correctly selected (panels A and C on the left) and when in the previous trials the distractor was initially selected (panels B and D on the right), and when prior selection color was red (upper panels A and B) and when the prior selection color was white (bottom panels C and D). The critical result is illustrated in panel (A). Error bars reflect within-subject standard error (Cousineau, 2005). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
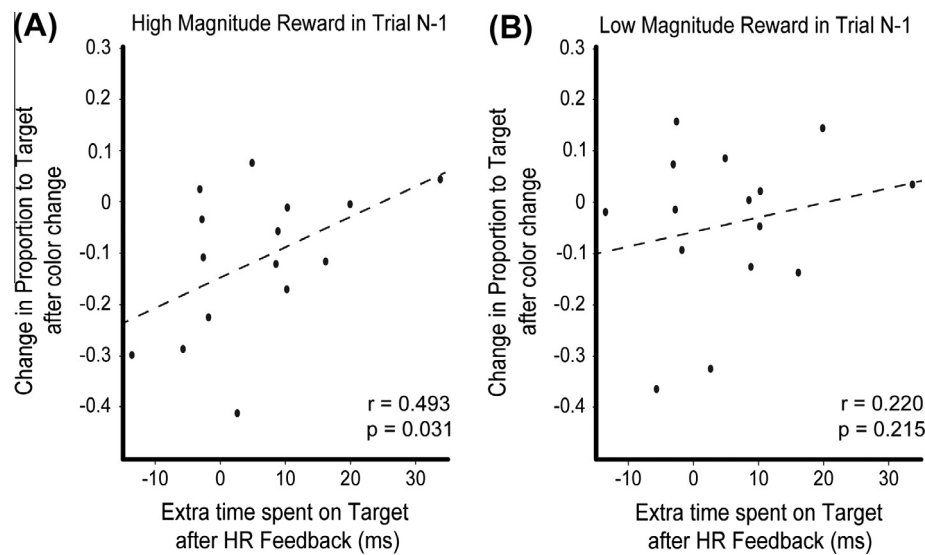
Fig. 3. Relationship between time spent on reward feedback in trial $N-1$ and the proportion of eye movements directed to the target in trial n, where (A) high magnitude reward was received in trial $N-1$, and (B) low magnitude reward was received in trial $N-1$. Broken lines reflect least-square fit of the data.

color priming effect. The values thus generated were Pearson correlated with the dwell time measure, garnering the results illustrated in Fig. 3. A strong relationship was identified when feedback had indicated high-magnitude reward, indicating that those who spent less time on the high-magnitude reward feedback subsequently showed a larger impact of reward on oculomotor selection (Pearson r: 0.493, $p = 0.031$; Fig. 3A). No corresponding relationship was revealed when feedback had indicated low-magnitude reward (Pearson r: 0.217, $p = 0.220$; Fig. 3B). The difference between these correlations was significant, $t(12) = 10.1$, $p < 0.001$ (Chen & Popovich, 2002; Stieger, 1980).

4. Discussion

The central finding is illustrated in Fig. 2A: high-magnitude reward reinforced the representation of the target such that the eyes were preferentially deployed to this object in the next trial. This increased the likelihood that the eyes would be correctly deployed to the target when it was this stimulus that had carried the unique color, but it also increased the likelihood that the distractor would be selected when the unique color characterized this nontarget.

In contrast to prior investigations of reward and oculomotor capture (e.g. Anderson & Yantis, 2012; Theeuwes & Belopolsky, 2012) the reward-priming effect on saccadic capture observed here is very unlikely to be strategic or top-down in nature, or rely in any way on the implicit recognition of statistical regularities in the reward schedule. Our design was such that the unique color randomly characterized either the target or distractor in each trial. Participants knew that stimulus color was task-irrelevant and that the specific visual characteristics of the display did not predict reward magnitude. There was thus no explicit or implicit motivation for them to establish a top-down attentional set based on color. In contrast, there was strong motivation for them to establish a set for the specific horizontal orientation of the target, which never changed. The capture of the eyes indexed here, and its modulation by reward, is in spite of this top-down set.

Selective bias for the reinforced color was observed only when the target selected in trial $n-1$ had unique, high-salience red color (cf. Fig. 2A and C). Rewarded selection of a white target, which

shared color with all 287 background stimuli, had a nominal benefit on subsequent selection of a target characterized by the same color (Fig. 2C, no color change condition), but did not cause a white distractor to draw attention or interfere in search for the target in the next trial (Fig. 2C, color change condition). This makes sense: reward-priming of a color shared with many non-target items would not cause a dramatic increase in the relative salience of the white orientation-singleton distractor.

One of the motivations for the current study was the idea that reinforcement of target selection would have a qualitatively different impact when selection had been efficient and the eyes had been directly deployed to the target, as compared to when selection had been inefficient and the eyes had first been captured to the distractor. The results do in fact show a very different pattern between these conditions: when participants directly selected the target, reward primed the unique target color such that subsequent stimuli with that color became salient (Fig. 2A). This pattern was entirely absent when the eyes had been initially captured in the preceding trial (Fig. 2B). Thus, only unique features associated with correct selection of the target resulted in a subsequent reward-priming effect; features associated with incorrect selection of the distractor did not modulate performance.

We additionally approached the data with an interest in how variability in the processing of reward feedback might predict subsequent behavior. Existing work has shown that the quality of feedback processing – as indexed in an electrophysiological signature of activity in the anterior cingulate cortex – can predict the magnitude of subsequent behavioral reward-priming (Hickey, Chelazzi, & Theeuwes, 2010a). Those results demonstrated a positive relationship that was driven by variability in the response to high-magnitude reward feedback. Here we observe a negative relationship: participants whose eyes remained on the high-magnitude reward feedback were less likely to misallocate their eyes to a distractor when it came to be characterized by the reward-associated red color in the next trial (see Fig. 3A). Those who show less evidence of differential processing of reward feedback show the greatest effect of reward magnitude on subsequent behavior.

We speculatively interpret this surprising pattern as evidence of individual variability in the experience of reward. We have sug-

gested here and elsewhere that the binding of rewarding experience to irrelevant features like color is an automatic, low-level phenomenon that has evolutionary origins (e.g. Hickey, Chelazzi, & Theeuwes, 2010a; Hickey & van Zoest, 2012). Results suggest that such reward-priming can be insensitive to strategic control, in that reward-associated colors remain salient even when participants know that stimuli characterized by these colors are very unlikely to be task relevant (Hickey, Chelazzi, & Theeuwes, 2010a). However, the automaticity of this effect is not contingent on the simple presentation of reward feedback: the feedback has to activate the neural reward system to be effective. In other words, there must be an experience of reward for there to be a subsequent effect on vision. Our feeling is that observed variance in reward priming often reflects underlying variance in the strength and quality of this experience of reward, and this idea has found support in results showing that the strength of direct priming can be predicted by a personality questionnaire designed to judge reward sensitivity (Hickey, Chelazzi, & Theeuwes, 2010b) and by a measure of reward processing in cortex (Hickey, Chelazzi, & Theeuwes, 2010a). In the current results, it appears that those who dwell on the feedback longer may have a different, potentially 'colder' experience of the reward.

During the editorial process a reviewer suggested that the individual variability observed here might be related in nature to known differences in reward's effect on vision resulting from variability in working memory capacity (see Anderson, Laurent, & Yantis, 2011a, 2011b). It seems to us that this would be a graceful and compelling account if our design had relied on statistical regularities between stimulus and outcome. Under these circumstances, we might infer that the observed individual differences reflected variance in the ability to store and access these 'rules'. However, given that reward was random in our design, and there were no such rules, the task does not strike us as one that taxes working memory, and our feeling is that variability in reward sensitivity is a likelier causative agent.

The individual variability in human behavior that we observe in the current data may have a parallel in the animal approach behavior literature. There, between-animal variability in behavior during and after Pavlovian learning is well documented: some animals that have learned to associate a conditioned stimulus (such as a light) to an unconditioned stimulus (such as the delivery of food) will approach and interact the conditioned stimulus when it is activated ('sign-trackers'), whereas others will approach and wait at the location where the unconditioned stimulus will be appear ('goal-trackers'; e.g. Robinson & Flagel, 2009). Though the association between unconditioned and conditioned stimuli in this work is consistent (unlike the random reward schedule employed in the current study) the behavior of sign-trackers does appear automatic and non-strategic in nature: the animals know that food will never appear at the location of the conditioned stimulus, and moving to this location is counter-strategic in that it delays actual food consumption. This propensity to approach the conditioned stimulus in spite of the cost has been related to stronger attribution of incentive salience to the conditioned stimulus apparatus and location. The conditioned stimulus appears to become motivationally salient for sign-trackers, subsequently causing it to act as a better conditioned reinforcer (Robinson & Flagel, 2009) and to more efficiently reinstate reward-seeking behavior following extinction (Yager & Robinson, 2010). No corresponding effects are observed in goal-trackers. Such a misattribution of motivational salience may underlie the non-strategic reward priming effect identified in the current study.

5. Conclusions

We demonstrate that the experience of reward can prime the representation of task irrelevant features – in this case unique color – causing objects with these features to be preferentially selected by the eyes. This does not appear to be a strategic effect, but it does appear to be sensitive to the quality of target selection: when target selection was inefficient, and the eyes had first been captured to a distractor, reward caused no subsequent priming of the distractor color. We further show that there is substantial individual variability in the reward-priming of saccadic selection that may have interesting parallels in animal approach behavior.

Acknowledgments

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