THE EFFECT OF REWARD ON PREVIEW BENEFIT

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Reward Does Not Modulate the Preview Benefit in Visual Search

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Abstract

Preview benefit refers to faster search for a target when a subset of distractors is seen prior to the search display. We investigated whether reward modulates this effect. Participants identified a target among non-targets on each trial. On “preview” trials, placeholders occupied half the search array positions prior to the onset of the full array. On “non-preview” trials, no placeholders preceded the full search array. On preview trials, the target could appear at either a placeholder position (old-target-location condition) or a position where no placeholder had been (new-target-location condition). Critically, the color of the stimulus array indicated whether participants would earn reward for a correct response. We found a typical preview benefit, but no evidence that reward modulated this effect, despite a manipulation check showing that stimuli in the reward-signaling color tended to capture attention on catch trials. The results suggest that reward learning does not modulate the preview benefit.

Keywords: preview benefit, reward, spatial attention, visual search

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Our visual world is filled with a vast amount of complex information, and yet we have a limited capacity for processing multiple items simultaneously. Selective attention refers to the set of cognitive mechanisms that operate to improve the efficiency of search under these conditions, by enhancing information that is relevant to the searched-for item and suppressing irrelevant information. Traditionally, studies have proposed a model of visual selective attention that includes goal-directed (top-down) and stimulus-driven (bottom-up) mechanisms (e.g., Corbetta & Shulman, 2002; Theeuwes, 2010). However, more recent studies suggest that allocation of attention can also be influenced by our prior experience with stimuli, and in particular by learning about the relationship between stimuli and motivationally significant events such as rewards and punishments (Awh, Belopolsky, & Theeuwes, 2012; Failing & Theeuwes, 2018; Le Pelley, Mitchell, Beesley, George, & Wills, 2016; Theeuwes, 2018, 2019; Watson, Pearson, Wiers, & Le Pelley, 2019).

The effect of reward on attention has been demonstrated using many kinds of experimental tasks in a variety of situations (Anderson, 2013, 2016; Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Ruz, Le Pelley, Kompier, Mait, & Bijleveld, in press). A typical finding is that learned associations between stimulus features and rewards influence what we attend to. For example, a color that has previously predicted reward can come to elicit attentional or oculomotor capture (e.g., Anderson, Laurent, & Yantis, 2011; Le Pelley,

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Pearson, Griffiths, & Beesley, 2015). Attentional capture by reward-associated stimuli occurs even when it is counterproductive: people reflexively attend to reward-signaling stimuli even when doing so negates the reward (e.g., Failing, Nissens, Pearson, Le Pelley, & Theeuwes, 2015; Le Pelley et al., 2015; Pearson, Donkin, Tran, Most, & Le Pelley, 2015). Taken together, these findings suggest that—beyond influences of behavioral goals or physical salience—reward-associated stimuli receive attentional priority and cause attentional or oculomotor biases.

Although there is a growing literature on how reward affects the deployment of attention, few studies have explored how reward influences the dynamics of attention from one moment to the next. Visual information changes over time, and in some situations, we may be able to take advantage of these dynamics in order to improve the efficiency of attentional selection. For example, studies using a *preview search* paradigm (see Donk, 2006; Watson, Humphreys & Olivers, 2003) to examine how changes in a scene affect attention have consistently reported a search benefit as a result of previewing stimuli (e.g., Watson & Humphreys, 1997; Kiss & Eimer, 2011; Theeuwes, Kramer, & Atchley, 1998). These studies demonstrated that when participants saw a subset of search array items in advance, they were subsequently better (faster/more accurate) at finding a target, compared to when all of the search stimuli appeared simultaneously, a finding termed the *preview benefit* (e.g., Watson & Humphreys, 1997, 2000). Moreover, when participants previewed some of the locations in

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77 which search items would subsequently appear, they were slower to find the target when it
78 appeared in one of these previewed locations than when it appeared in a new location (e.g.,
79 Atchley, Jones, & Hoffman, 2003; Donk & Theeuwes, 2003).

80 The source of preview benefit has been a topic of debate: it has been argued to reflect
81 attentional suppression of previewed stimulus locations (e.g., Watson & Humphreys, 1997),
82 temporal segregation between previewed stimuli and those appearing subsequently (e.g.,
83 Jiang, Chun, & Marks, 2002), or attentional capture by new stimuli that appear in the final
84 search display (onset capture, e.g., Belopolsky, Theeuwes, & Kramer, 2005; Donk &
85 Theeuwes, 2001). Although the mechanism underlying preview benefit remains open to
86 debate, the empirical finding that previewing a subset of stimuli improves search
87 performance is robust.

88 The current study investigated whether reward history can influence the preview
89 benefit effect. We used a preview search procedure based on that of Osugi, Hayashi, &
90 Murakami (2016): on each trial participants were required to respond to a target in a search
91 display, but on some trials (termed preview trials) this was preceded by a preview display
92 containing placeholders that marked the locations of half of the items that would appear in
93 the subsequent search display. On these preview trials, the target in the search display was
94 equally likely to appear at a location where one of the previewed placeholders had appeared
95 (*old-target-location* condition) or in a location that had been empty in the preview display

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(*new-target-location* condition). Importantly, in this experiment the color of the placeholders and search array items changed from trial to trial, with this color signaling whether or not an accurate search response would earn reward.

In line with previous research (e.g., Osugi et al., 2016; Watson & Humphreys, 1997), we anticipated an overall preview benefit effect: for the new-target-location condition (in which a target appeared at a position that had been unoccupied in the preview display), we expected to observe better search performance in preview trials than in non-preview trials. Moreover, on preview trials we predicted faster response times in the new-target-location condition, relative to the old-target-location condition (e.g., Atchley et al., 2003; Donk & Theeuwes, 2003; Osugi et al., 2016). The critical question was whether these preview effects would be modulated by the reward-signaling status of the stimuli. There are various pathways through which reward might be expected to influence performance in this procedure. Notably, evidence suggests that reward-signaling stimuli are more likely (than non-reward stimuli) to capture and hold attention (Anderson, 2016; Failing & Theeuwes, 2018; Le Pelley et al., 2016; Watson, Pearson, Theeuwes, Most & Le Pelley, 2020) and are particularly difficult to suppress via inhibitory processes (e.g., Pearson, Watson, Cheng & Le Pelley, 2020; Wang, Duan, Theeuwes & Zhou, 2014). Hence, we hypothesized that participants may have difficulty disengaging attention from reward-signaling stimuli in the preview display, which would enhance performance when the target subsequently appeared at one of these previewed

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locations (i.e., old-target-location trials) and impair performance when the target appeared at a new location. On this account, preview benefit should be reduced for reward-signaling stimuli relative to no-reward stimuli.

An alternative possibility is that reward might act in a top-down fashion to enhance the efficiency of visual search processes. On preview trials, the color of placeholders in the preview display informed participants of the (un)availability of reward for a correct response to the upcoming search target. As such, participants may be motivated to prepare for efficient search on preview trials where the stimuli signaled reward (cf. Failing & Theeuwes, 2017). This account would suggest that reward should enhance the standard preview-benefit effect: the performance advantage when a preview is provided (relative to no-preview trials) should be greater when that preview signals the availability of reward. Furthermore, the motivational boost provided by pre-knowledge of the availability of reward could therefore enhance performance in preview trials of the reward condition (relative to the no-reward condition) regardless of the location of the target in the subsequent search display. That is, if participants ‘try harder’ when they know reward will be at stake, then they may be generally faster to find the target regardless of whether it appears in an old or a new location. Hence, this motivational account would predict better performance on preview trials of the reward condition than the no-reward condition regardless of target location.

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Experiment 1**Method**

Participants. Previous studies of reward-based attention (Le Pelley et al., 2015; Watson et al., 2019) have revealed medium to large effect sizes ($d_z = 0.4$ to 1.12). We aimed to test at least 31 participants, as a power analysis conducted with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that a sample of this size would give power of .90 to detect an effect size of $d_z = 0.60$ for reward effects for within-participants t-tests. A total of thirty-two students from UNSW Sydney participated in Experiment 1 for course credit. They reported normal or corrected-to-normal visual acuity and were screened for color vision (Ishihara, 1917). One participant could not complete the task due to computer error, which resulted in data loss. Data from the remaining 31 participants (17 females; age $M = 19.5$ years, $SD = 1.3$ years) were included in analyses. All experiments reported in this article were approved by the Human Research Ethics Advisory Panel (Psychology) of UNSW Sydney, and all participants provided informed consent before the experiment.

Apparatus. Participants were tested individually, with stimuli presented on a 23-inch monitor (Alienware AW2310, 1920×1080 resolution, 60-Hz refresh rate) at distance of ~45 cm. Stimulus presentation was controlled by MATLAB using Psychophysics Toolbox extensions (Brainard, 1997). Participants made responses using a standard keyboard.

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Stimuli. The task of Experiment 1 was based on that used by Osugi et al. (2016, Experiment 3). All stimuli were presented on a black background (see Fig. 1). The fixation display consisted of a white fixation dot ($0.23^\circ \times 0.23^\circ$ of visual angle) at the center of the screen. In this task, stimuli were ‘digital display’ letters (i.e., made by removing lines from a figure-eight shape) subtending 2° in height and 1° in width. Figure eights were used as placeholders in the preview display. The search display contained sixteen letters: one target (either “H” or “U”), and fifteen distractors (taken from the set of “A”, “C”, “E”, “F”, “O”, “P”, and “S”: six of these letters appeared twice in the display, and the seventh [randomly chosen on each trial] appeared three times). These letters were presented at equidistant positions around an imaginary circle with a radius of 8° visual angle. All letters in a given search display had the same color (either pink or green), and the color of the placeholders in the preview display (if it was shown) always matched the color of the letters in the search display. The feedback display showed the number of reward points earned on the current trial.

Design. In Experiment 1, there were three independent variables that were manipulated in a within-participants design: the trial type (preview or non-preview), the reward outcome (reward or no-reward), and the target position (old or new). The first variable was whether the preview display was presented or not before the search display. The second variable was whether the color of the stimuli presented on a particular trial signaled that a correct response to the target in the search display would earn a reward or not (10 points or 0

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points). For half of participants, green stimuli signaled that a reward was available and pink stimuli signaled that no reward was available; for remaining participants this assignment was reversed. The third variable was whether a target appeared at a position that had been occupied by a placeholder in the preview display (old-target-location condition) or at a position that had not been occupied by a placeholder (new-target-location condition). Note that the target position in non-preview trials was dummy-coded.

Procedure. Each trial began with the fixation display for 500 ms. In the non-preview condition, all sixteen letters appeared simultaneously in the search display. In the preview condition, following the fixation display, eight placeholders appeared in the preview display for 1000 ms before the search display appeared. Participants had to identify which target letter (H or U) was present in the search display by pressing the “z” or “m” keys with right and left index fingers, respectively. The search display appeared for 5,000 ms or until response. The screen then blanked for 300 ms before the feedback display appeared for 1300 ms. The next trial then began after a blank inter-trial interval of 600 ms.

Importantly, we manipulated the reward available for a correct response on each trial. Specifically, whether or not reward was available was signaled by the color of the letters in the search display (and the color of the placeholders in the preview display on preview trials). If stimuli appeared in the reward-signaling color (pink or green, counterbalanced across participants), a correct response to the search display would earn reward (the feedback

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display stated: “+10 points”); if stimuli appeared in the no-reward color (green or pink) a correct response did not earn reward (“+0 points”). If participants made an error or no response was registered within the search time window (i.e., 5,000ms), feedback stated “INCORRECT” or “TOO SLOW” respectively. Feedback was presented in white text in the center of the screen.

Instructions at the beginning of the task noted that participants should respond as quickly and accurately as possible, and that reward points could be earned only for correct responses. Participants were also told about color-reward associations as follows: “In this task, a color of letters is associated with the magnitude of reward. If there are [pink/green] letters in the display, you will receive 10 points, and if there are [green/pink] letters in the display, you will receive 0 points”. Reward points were purely nominal and had only intrinsic value in Experiment 1 – they were not translated into (for example) a monetary reward. However, previous research indicates that intrinsic, points-based reward is nevertheless motivating to participants and can result in modulation of attention (e.g., Watson et al., 2019, 2020).

The experiment started with a practice session of 32 trials without reward, followed by 8 experimental blocks of 64 trials each, yielding 512 trials in total. The target letter (H or U), the reward outcome (reward or no-reward), the trial type (preview or non-preview), the target position (old or new), and the target positions in the display (16 possible locations)

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210 were balanced across trials, and trials were presented in a random order. The position of each
211 distractor letter was determined randomly in each trial. Between blocks, participants took a
212 short break and saw a screen indicating the number of points earned in the previous block, as
213 well as the mean number of points earned per block up to that point in the task. The
214 experiment lasted for about 60 minutes.

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Fig 1. Trial sequence of the task used in Experiments 1 and 2. Participants were required to identify which target letter (“H” or “U”) was present in the search display. In the preview condition, the placeholders were presented for 1,000 ms before the search display. The feedback display indicated reward points received on the current trial.

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Fig 2. Examples of the trial type (preview or non-preview) and target position (old or new) conditions used in Experiments 1 and 2. In the preview condition, the search display was preceded by a placeholder display; in the non-preview condition, no preview display appeared. In the old-target-location condition, the search target (the letter H or U) appeared in the location of one of the placeholders in the preview display; in the new-target-location condition, the target appeared in a location that had been empty in the preview display. Target position (old versus new) was dummy-coded in non-preview trials.

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Results

Timeout trials (i.e., no response within 5,000 ms; 0.47% of all trials) were discarded from analyses of response time and were coded as incorrect trials for analyses of accuracy. For simplicity, and because the timeout placed an upper limit on response times, we did not perform further outlier removal for the analyses reported here; however we verified that the pattern of findings was unchanged if response times lying more than three standard deviations from the mean of the respective condition for each participant were removed (average 1.41% of correct trials).

Figure 3a shows mean response times for correct responses averaged across all blocks in Experiment 1. A 2 (reward outcome: reward/no-reward) $\times$ 2 (trial type: preview/non-preview) $\times$ 2 (target position: old/new) repeated-measures ANOVA revealed that the main effects of reward outcome, $F[1, 30] = 1.74, p = .197, \eta_p^2 = .055$, and trial type were not significant, $F[1, 30] = 1.67, p = .206, \eta_p^2 = .053$. However, there was a main effect of target position, $F[1, 30] = 7.98, p = .008, \eta_p^2 = .210$, which was qualified by a trial type $\times$ target position interaction, $F[1, 30] = 14.50, p < .001, \eta_p^2 = .326$. No other interactions were significant ($ps > .29$). Analysis of simple effects underlying the trial type $\times$ target position interaction showed faster response times in the new-target-location condition than the old-target-location condition on preview trials, $F[1, 30] = 12.71, p = .001, \eta_p^2 = .298$, in line with previous studies of the preview effect (e.g., Atchley et al., 2003; Donk & Theeuwes, 2003;

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Osugi et al., 2016). There was no difference in response times based on the target position on non-preview trials, $F[1, 30] = 0.00$, $p = .952$, $\eta_p^2 = .000$, which is unsurprising since target position was dummy coded on non-preview trials. Orthogonal analyses showed that, for the new-target-location condition, response times in preview trials were significantly faster than that in non-preview trials, $F[1, 30] = 15.07$, $p = .001$, $\eta_p^2 = .334$, demonstrating a typical preview benefit as observed in previous studies (in which all trials were effectively ‘new-target-location’ trials, e.g., Watson & Humphreys, 1997). In the old-target-location condition, response times did not differ significantly on preview versus non-preview trials, $F[1, 30] = 0.87$, $p = .360$, $\eta_p^2 = .028$. That is, no preview benefit (or cost) was observed when the target replaced one of the placeholder elements in the preview display.

The analyses reported above indicated that the reward-signaling status of the stimuli did not significantly influence response times, either as a main effect or through interaction with other factors. In order to quantify support for the null hypothesis, we conducted a Bayesian analysis of these data using JASP (Version 0.13; JASP Team, 2020) with the default Cauchy prior. Specifically, we calculated “inclusion Bayes Factors across matched models” for the main effect of reward outcome, and interactions involving this factor: in each case, these Bayes Factors indicate the weight of evidence across candidate models including the effect of interest, versus the weight of evidence across otherwise-matched models that exclude the effect of interest. This analysis found moderate evidence in favor of the null

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hypothesis for (1) the main effect of reward outcome, $BF_{01} = 3.016$; (2) the reward outcome $\times$ trial type interaction, $BF_{01} = 3.678$; (3) the reward outcome $\times$ target position interaction, $BF_{01} = 4.043$; and (4) the three-way interaction, $BF_{01} = 3.145$. That is, in each case the data provided over three times greater support for the null hypothesis than for the alternative hypothesis (Lee & Wagenmakers, 2013).

Figure 3b shows accuracy data from the search task; accuracy was generally high and similar across conditions. ANOVA analysis of these data revealed no significant main effects of reward outcome, $F[1, 30] = 0.14, p = .709, \eta_p^2 = .005$, or trial type, $F[1, 30] = 1.02, p = .321, \eta_p^2 = .033$, but a marginal main effect of target position emerged, $F[1, 30] = 3.13, p = .087, \eta_p^2 = .095$, with a trend towards lower accuracy in the old-target-location condition than the new-target-location condition. No other interactions were significant ($ps > .16$). These results suggest no evidence of a speed-accuracy trade-off.

We also conducted a Bayesian repeated-measures ANOVA in order to assess evidence for null effects of reward outcome on accuracy. Inclusion Bayes Factors across matched models found support for the null hypothesis over the alternative hypothesis for: (1) the main effect of reward outcome, $BF_{01} = 6.728$; (2) the reward outcome $\times$ trial type interaction, $BF_{01} = 5.272$; (3) the reward outcome $\times$ target position interaction, $BF_{01} = 2.866$; and (4) the three-way interaction, $BF_{01} = 1.178$.

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Fig 3. (a) Mean response times and (b) accuracy as a function of reward outcome (reward/no-reward), trial type (preview/non-preview), and target position (old or new) in Experiment 1. Error bars show within-subject standard error of the mean (Morey, 2008). Note that the target position in non-preview trials was dummy-coded.

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307 **Discussion**

308 In Experiment 1, we examined whether reward associations modulate preview benefit.
309 Consistent with previous studies (e.g., Donk & Theeuwes, 2003), we found that participants
310 were generally faster to respond to targets that appeared at a new position in the search
311 display (i.e., a position that had not been occupied in the preview display) compared to an old
312 position (i.e., a position that had been occupied by a placeholder in the preview display).
313 Moreover, in line with previous findings (e.g., Watson & Humphreys, 1997), we confirmed a
314 typical preview benefit (faster responses on preview than non-preview trials) in the new-
315 target-location condition. However, no preview benefit was observed in the old-target-
316 location condition: here participants were no faster on preview trials than non-preview trials.

317 Notably, and contrary to our expectations, reward seemed to have no effect on
318 performance: on both old- and new-target-location trials, response times were similar
319 regardless of whether the color of the stimuli signaled that reward was available for a correct
320 response or not. Likewise, the magnitude of the preview benefit (i.e., difference in
321 performance on preview versus non-preview trials) did not differ between the reward
322 outcomes. Before attaching too much significance to these null findings, however, it is
323 important to rule out the (relatively uninteresting) possibility that participants did not learn
324 the color–reward associations in Experiment 1 (in which case they could not be expected to
325 influence behavior), or that the rewards used in this task were not motivating to participants.

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To this end, Experiment 2 replicated Experiment 1 but added occasional *color-test* trials as a manipulation check, in which both reward and no-reward colors were present in the search display, to diagnose whether participants had learned the color-reward associations and whether the rewards could modulate attention. In some of these color-test trials the target in the search display appeared in the reward-signaling color while one of the distractors appeared in the no-reward color, with all other letters being gray: these were termed reward-target trials (see Fig 4). In other trials, the target appeared in the no-reward color and a distractor appeared in the reward color (reward-distractor trials). Many previous studies have demonstrated that reward-signaling stimuli are more likely to capture attention than are no-reward stimuli (e.g., Bucker, Silvis, Donk, & Theeuwes, 2015). Consequently, in the current task, if participants had learned the color–reward associations—and these associations could modulate attention—then we would expect faster responses to the target on reward-target trials (since the target should be more likely to capture attention than the colored distractor) than on reward-distractor trials (since here the target should be less likely to capture attention than the colored distractor).

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Experiment 2**Method**

Participants. Thirty-four UNSW Sydney students (21 females, age $M = 19.3$ years, $SD = 1.5$ years) participated in Experiment 2 for course credit; none had taken part in Experiment 1. All reported normal or corrected-to-normal visual acuity and were screened for color vision (Ishihara, 1917).

Apparatus, stimuli, design, and procedure. Apparatus, stimuli, design, and procedure were identical to Experiment 1, with the following changes.

In Experiment 2, we added *color-test trials* as a manipulation check, to assess participants' learning of the color-reward associations (and the ability of these associations to impact behavior). Color-test trials never featured a preview display. On color-test trials, all stimuli in the search display except for the target and one of the distractors were colored gray (see Fig. 4). In the reward-target condition of color-test trials, the target appeared in the reward-signaling color, and the colored distractors appeared in the no-reward color. In the no-reward-target condition, this mapping was reversed. Just as for 'standard' trials, participants were required to respond according to the identity of the target (H or U) as quickly as possible on color-test trials. Participants received rewards based on the color of a target letter; if a target appeared in the reward color (green or pink, counterbalanced across participants), a correct response earned "+10 points", whereas if a target appeared in the no-reward color

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(pink or green, counterbalanced across participants), no reward was given (“+0 points”). As in Experiment 1, reward points were nominal.

Participants initially practiced 40 trials without reward (32 ‘standard’ trials as in Experiment 2, and 8 color-test trials, intermixed in random order). The main body of the experiment then comprised 10 blocks of 64 trials each, yielding 640 trials in total. Of these, 512 were ‘standard’ trials as in Experiment 2, and 128 were color-test trials: trials were intermixed and presented in random order. Across the 128 color-test trials, the reward type (reward-target or reward-distractor), target letter (H or U), and target position (one of 16 locations) were balanced. The location of the colored distractor on color-test trials was randomly chosen with the constraint that it always appeared five or more locations away from the target. The experiment lasted for around 70 minutes.

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Fig 4. Examples of color-test trials as used in Experiment 2, for a participant for whom pink is the reward-associated color and green is the no-reward color. On reward-target trials, the target (“H” in this case) appeared in the reward-associated color, and a distractor that was located at least five locations from the target appeared in the no-reward color. On reward-distractor trials, the target appeared in the no-reward color and the opposite distractor appeared in the reward-associated color. All other letters were colored gray.

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Timeout trials (i.e., no response within 5,000 ms; 0.28% of all trials) were discarded from analyses of response time and were coded as incorrect trials for analyses of accuracy. As in Experiment 1, we did not perform further outlier removal for the analyses reported here, but we verified that the pattern of findings was unchanged if response times lying more than three standard deviations from the respective mean for each participant were removed (average 1.36% of standard trials, and 1.91% of color-test trials).

Standard trials. Figure 5a shows mean response times for correct responses on ‘standard’ (preview and non-preview) trials averaged across all blocks in Experiment 2. As in Experiment 1, these data were analyzed using 2 (reward outcome: reward/no-reward) $\times$ 2 (trial type: preview/non-preview) $\times$ 2 (target position: old/new) ANOVA. The results of this analysis closely mirrored those of Experiment 1. There were no main effects of trial type, $F[1, 33] = 0.30, p = .586, \eta_p^2 = .009$, or reward, $F[1, 33] = 0.10, p = .751, \eta_p^2 = .003$, but there was a significant main effect of target position, $F[1, 33] = 16.46, p < .001, \eta_p^2 = .333$, which was qualified by a trial type $\times$ target interaction, $F[1, 33] = 13.50, p < .001, \eta_p^2 = .290$. No other interactions were significant ($ps > .12$). Analysis of simple effects underlying the trial type $\times$ target interaction revealed faster response times in the new-target-location condition than the old-target-location condition on preview trials, $F[1, 33] = 18.57, p < .001, \eta_p^2 = .360$. There was no difference in response times based on the target position on non-preview trials,

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as expected, $F[1, 33] = 0.12, p = .732, \eta_p^2 = .004$. For the new-target-location condition, response times on preview trials were significantly faster than on non-preview trials, $F[1, 33] = 4.79, p = .036, \eta_p^2 = .127$, demonstrating a preview benefit. One difference from the findings of Experiment 1 is that in Experiment 2 a response time difference in the old-target-location condition emerged: here, responses were significantly *slower* on preview trials than on non-preview trials, $F[1, 33] = 6.67, p = .014, \eta_p^2 = .168$, suggesting a ‘preview impairment’ (i.e. costs of previewing stimuli). Notably, the three-way interaction between reward, trial type, and target position was not significant, $F[1, 33] = 0.00, p = .976, \eta_p^2 = .000$, suggesting that reward did not significantly modulate preview benefit.

As in Experiment 1, Bayesian repeated-measures ANOVA was used to calculate inclusion Bayes Factors across matched models for effects of reward outcome on response times. This analysis revealed moderate evidence in favor of the null hypothesis over the alternative for: (1) the main effect of reward outcome, $BF_{01} = 7.551$; (2) the reward outcome $\times$ trial type interaction, $BF_{01} = 2.248$; (3) the reward outcome $\times$ target position interaction, $BF_{01} = 4.851$; and (4) the three-way interaction, $BF_{01} = 4.025$.

Figure 5b shows corresponding accuracy data. ANOVA analysis of these data revealed no main effects of reward, $F[1, 33] = 0.29, p = .592, \eta_p^2 = .009$, trial type, $F[1, 33] = 0.93, p = .342, \eta_p^2 = .027$, or target position, $F[1, 33] = 0.77, p = .385, \eta_p^2 = .023$. Moreover, no two-way ($ps > .18$) or three-way interactions were found, $F[1, 33] = 0.46, p = .501, \eta_p^2 = .014$.

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These findings suggest that the pattern of response time differences did not reflect a speed-accuracy trade-off. Bayesian repeated-measures ANOVA analysis of accuracy data revealed moderate evidence in favor of the null hypothesis over the alternative for: (1) the main effect of reward outcome, $BF_{01} = 6.400$; (2) the reward outcome $\times$ trial type interaction, $BF_{01} = 1.937$; (3) the reward outcome $\times$ target position interaction, $BF_{01} = 5.669$; and (4) the three-way interaction, $BF_{01} = 3.832$.

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Fig 5. (a) Mean response times and (b) accuracy as a function of reward outcome (reward/no-reward), trial type (preview/non-preview), and target position (old or new) on ‘standard’ (i.e., non-color-test) trials of Experiment 2. Error bars show within-subject standard (Morey, 2008). Target position in non-preview trials was dummy-coded.

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Color-test trials. Figure 6a shows response times for correct responses on color-test trials, which were designed to provide a manipulation check for the effectiveness of color-reward associations. Responses to the target were significantly faster on reward-target trials (864 ms) than on reward-distractor trials (928 ms), $t(33) = 3.38$, $p = .002$, $d_z = 0.35$, 95% CI [25.31, 101.86]. Analysis of accuracy data (see Fig 6b) revealed that the difference between the reward-target (95.7%) and the reward-distractor conditions (94.9%) was not significant, $t(33) = 1.21$, $p = .237$, $d_z = 0.21$, 95% CI [-2.22, 0.57], suggesting that the observed difference in response times did not reflect a speed-accuracy trade-off.

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Fig 6. (a) Mean response times and (b) accuracy by reward conditions on color-test trials of Experiment 2. Error bars show within-subject standard error of the mean (Morey, 2008).

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Discussion

Experiment 2 replicated the manipulations of Experiment 1 as they pertained to the preview benefit, while also including a manipulation check for the ability of color-reward associations to influence shifts of attention in this task. With regard to the trial types carried over from Experiment 1, results were similar to those we observed previously. Once again, on preview trials we observed faster response times in the new-target-location condition than the old-target-location condition. We also observed a preview benefit in the new-target-location condition (faster responses on preview trials compared to non-preview trials). The only difference from Experiment 1 was that Experiment 2 found a ‘preview impairment’ in the old-target-location condition: previewing stimuli before the search display caused a search cost when the target subsequently appeared at a previewed position. The reason for this difference between experiments is unclear, though we note that even in Experiment 1 the pattern of means was consistent with a (non-significant) preview impairment in the old-target-location condition. Regardless, Experiment 2 was similar to Experiment 1 in again finding no evidence for modulation of the preview benefit (or preview impairment) by reward.

Importantly, whereas reward did not modulate the preview benefit, effects of reward *were* observed on color-test trials. Specifically, responses to the target were faster when it appeared in the reward-signaling color and a distractor appeared in the no-reward color,

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compared to when these mappings were reversed. This finding is consistent with previous research demonstrating that reward-associated stimuli are more likely to capture attention (see Failing & Theeuwes, 2018; Watson et al., 2019): on this account the target would be most likely to capture attention on reward-target trials, and the colored distractor would be most likely to capture attention on reward-distractor trials. Most importantly, the reward modulation observed on color-test trials demonstrates that (1) participants had learned the color-reward associations during the task, and (2) these rewards (and this knowledge) were sufficient to induce observable differences in search behavior. As such, the failure to observe an influence of reward on preview benefit in Experiment 2 (or, by extension, Experiment 1) cannot simply be explained as a consequence of participants having failed to learn reward associations in the task, or because the points-based reward system was insufficient to motivate behavior. Clearly participants *had* learned this reward information—and the nominal rewards were sufficient to modulate behavior—but participants did not (or could not) use the information to adapt their performance in response to previewed stimuli.

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Pooled Analysis

In both experiments, we showed that the reward-signaling status of the stimuli did not modulate the preview benefit. To ensure that the null effects observed here do not simply reflect a lack of power, we ran an additional analysis across pooled results from both experiments in the current study. Bayesian repeated-measures ANOVA analysis of response times revealed moderate evidence in favor of the null hypothesis over the alternative for: (1) the main effect of reward outcome, $BF_{01} = 8.702$; (2) the reward outcome $\times$ trial type interaction, $BF_{01} = 2.160$; (3) the reward outcome $\times$ target position interaction, $BF_{01} = 5.402$; and (4) the three-way interaction, $BF_{01} = 5.124$. We performed the same analysis for accuracy data and found moderate evidence in favor of the null hypothesis over the alternative for: (1) the main effect of reward outcome, $BF_{01} = 8.004$; (2) the reward outcome $\times$ trial type interaction, $BF_{01} = 5.705$; (3) the reward outcome $\times$ target position interaction, $BF_{01} = 5.024$; and (4) the three-way interaction, $BF_{01} = 4.442$. The results from the pooled analysis across both experiments thus support our findings that preview benefit is not modulated by the stimulus-reward association.

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Consequently, the inability of reward to modulate preview effects in these tasks cannot simply be ascribed to a failure of reward learning, since reward had no influence on preview benefit even when participants had demonstrably learned reward associations in the task. The Introduction described two possible routes through which reward might influence performance in the preview task, which are revisited below.

One possibility raised earlier was that reward might exert a general, top-down, motivational effect on search performance. The color of placeholders in the preview display effectively forewarned participants whether or not a reward would be available for a correct response to the search target. We reasoned that this may have encouraged participants to make greater preparations for efficient search when the preview display indicated that reward would be available, and/or make less effort when the preview showed that a correct response to the target would be unrewarded. This view anticipates that reward should enhance the preview benefit effect, with a greater performance advantage for preview versus no-preview trials in the reward condition than the no-reward condition. However, no such effect was observed.

Previous studies of attention (though not in the context of preview benefit) *have* demonstrated improved performance when participants knew in advance that reward was available versus being unavailable (Bucker & Theeuwes, 2014; Engelmann & Pessoa, 2007; Failing & Theeuwes, 2017; Small et al., 2005). In most of these studies, (un)availability of

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582 reward was manipulated at the level of blocks of trials: participants were informed that in the
583 upcoming block they would or would not be able to earn reward (Bucker & Theeuwes, 2014;
584 Engelmann & Pessoa, 2007; Small et al., 2005). It seems plausible that this kind of block-
585 level manipulation would emphasize motivational effects: e.g., participants might be more
586 likely to ‘switch off’ and respond randomly for blocks of trials in which they know that no
587 reward will be at stake. That said, Failing and Theeuwes (2017) found an effect of a *trial-*
588 *level* reward signal on search performance in their study. In their task, on each trial the pitch
589 of a 200-ms tone signaled whether high or low reward was available for a rapid response to a
590 target in a search display that appeared immediately after the tone; here the target was a
591 particular color of circle (e.g., blue) in a set of uniquely colored circles. Failing and Theeuwes
592 found faster responses when the tone signaled the availability of a high reward than when it
593 signaled a low reward; a finding that they attributed to participants’ greater top-down
594 attentional set for the target color when the tone signaled that high reward could be obtained.
595 Failing and Theeuwes’s findings stand in contrast to those of the current experiments, in
596 which a trial-level reward signal (the color of the 1000-ms preview display) had no effect on
597 performance. It may be significant in this regard that there were two possible search targets in
598 the current procedure (H or U) that varied randomly from trial to trial. As such it may have
599 been difficult for our participants to enhance search by strengthening a top-down attentional
600 set for the target, as they did not know what that target would be in advance. Future research

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could investigate this issue further, for example by using a preview task in which there is only one target (e.g., an H), and participants are required to locate that target in the search display.

The other possibility raised in the introduction built on the previously established finding that reward-signaling stimuli are more likely than non-reward stimuli to capture and hold attention (for reviews, see Anderson, 2016; Failing & Theeuwes, 2018; Le Pelley et al., 2016; Watson et al., 2019); a finding that gains support from data from the color-test trials of the current Experiment 2. We anticipated that participants might have difficulty in disengaging attention from reward-signaling stimuli in the preview display, which would enhance performance when the target subsequently appeared at one of these previewed locations (old-target-location trials) relative to when the target appeared in a new location. However, once again we did not see evidence of this pattern in the results: participants were faster on new-target-location trials than old-target-location trials of the preview condition, but this pattern did not vary as a function of the reward signaled by the preview stimuli. Various factors may have contributed to the failure of reward to influence performance here. One possibility is that the relatively long duration of the preview display (1000 ms) was sufficient for participants to disengage attention from the previewed placeholders regardless of whether or not they predicted reward. Moreover, such a long preview time might be insensitive to reward effects given that previous studies suggest that reward can affect attentional selection at an early stage of visual processing and in a similar way as physical salience (see Failing &

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620 Theeuwes, 2018; Pearson et al., 2016). These ideas could be tested in future studies by using
621 shorter preview durations. Another possibility relates to the relatively large number of items
622 in the search display of the current task (16 letters; for comparison, Failing and Theeuwes,
623 2017, had only 6 stimuli in their search display). Our heterogeneous search display in which
624 all stimuli were presented in the same color may have encouraged participants to use a serial
625 search process to find the target. That is, they may have commenced search by strategically
626 scanning stimuli that appeared in new-target-locations regardless of whether reward was
627 available or not. This serial search strategy might diminish any effect of delayed
628 disengagement from reward-signaling stimuli in the preview display by shifting attention
629 away from the stimuli that appeared in old-target-locations. Related to the ideas advanced in
630 the previous paragraph, our use of preview and search displays in which all stimuli appeared
631 in the same color raises the possibility that an influence of reward on attentional
632 *disengagement* from placeholders was counteracted by an influence on attentional *capture* by
633 stimuli at new locations in the search display. That is, appearance of a target (or any other
634 stimulus) at a new location creates an onset, and it is possible that capture by onset stimuli
635 may be enhanced when those stimuli appear in a reward-signaling color (versus a no-reward
636 color). This would tend to improve performance in the new-target-location condition relative
637 to the old-target-location condition, thus opposing the effect of reward on attentional
638 disengagement from previewed locations (which would tend to impair performance in the

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639 new-target-location condition relative to the old-target-location condition). This idea could
640 potentially be tested in future research using a procedure in which preview stimuli and
641 search-display stimuli appear in different colors, where one color is associated with reward
642 and the other is not. Trials in which the preview color signals reward while the search stimuli
643 appear in a neutral color should selectively emphasize any role of reward on disengagement.
644 By contrast, trials in which the preview stimuli appear in a neutral color and the search
645 stimuli appear in a reward-signaling color should selectively emphasize any influence of
646 reward on capture.

647 More generally, the ‘standard’ (i.e., preview and non-preview) trials of the current
648 experiments examined a situation in which the stimuli provided ‘global’ information about
649 the availability of reward. That is, the reward information was not spatially localized to a
650 subset of the stimuli and hence may not have selectively guided search – unlike the color-test
651 trials of Experiment 2, in which reward information was spatially localized to specific
652 stimuli. We showed that this global reward information had no effect on preview benefit, but
653 this does not rule out the possibility that preview benefit might interact with more localized
654 reward information; this remains a question for future research.

655 Setting aside the question of the effect of reward, we can also consider the source of
656 the (reward-independent) preview benefit observed in both Experiments 1 and 2. In the
657 current study, previewed stimuli did not predict target positions because targets were equally

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658 likely to appear in either old or new positions (see also Osugi et al., 2016). This sets our
659 procedure apart from many previous studies, which have used preview search paradigms in
660 which the target always appeared at a new position (e.g., Watson & Humphreys, 1997, 2000).
661 The design of these prior studies would potentially create a drive to suppress or inhibit
662 locations of previewed stimuli (since targets would never appear in these locations), and any
663 such suppression would tend to enhance performance on preview trials relative to non-
664 preview trials; that is, suppression could be a source of the observed preview benefit. By
665 contrast, our experimental design did not motivate participants to suppress stimuli in the
666 preview display because previewed stimuli were uninformative about target position.

667 Although we did not instruct our participants about the exact proportion of trials in which a
668 target appeared at a previewed position, they at least knew that suppressing these positions
669 was not always beneficial. In that sense, the preview benefit observed in the current study
670 seems not to reflect the operation of a top-down strategy, but instead suggests a relatively
671 automatic effect of previewed stimuli on attention. One possibility is that the preview benefit
672 observed under these conditions results from onset capture (see also Osugi et al., 2016). On
673 non-preview trials, onsets occur at the location of all stimuli in the search display, whereas on
674 preview trials onsets occur only at the locations of new stimuli. If onsets tend to capture
675 attention, this will tend to produce faster detection of the target on new-target-location trials
676 in the preview condition than the non-preview condition, since there are fewer competing

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677 onsets in the former case than the latter; the result observed in both of the current
678 experiments. It will also tend to produce slower detection of the target on old-target-location
679 trials in the preview condition than the non-preview condition, since the target will be a
680 salient onset in the latter but not the former – producing the ‘preview impairment’ observed
681 in Experiment 2. More generally, the distinction between procedures in which the target may
682 or may not appear at old (previewed) locations raises the possibility that participants’ search
683 strategy may change depending on the predictability of target positions by the preview
684 display, which is a limitation of the current study. Further studies are needed in order to
685 clarify whether a predictability of a target position affects reward effects by systematically
686 manipulating a probability of trials in the old/new target-location condition in a preview
687 search paradigm.

688 In sum, this study examined the effect of ‘global’ reward information on preview
689 benefit and showed no evidence of reward modulation of preview benefit. While a search
690 benefit was observed as a result of previewing stimuli, reward outcomes did not seem to have
691 an influence on preview benefit. Whereas a manipulation check revealed that reward did
692 modulate the allocation of attention within static displays, one possibility is that reward exerts
693 less influence on mechanisms that integrate information across views in the service of
694 guiding attention from one moment to the next.

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