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Physically salient stimuli capture attention despite external motivation to ignore

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Abstract

Stimuli that are physically salient—e.g., brighter or differently colored to others in the visual scene—capture eye gaze and attention. Many studies have shown that color-singleton distractors slow visual search for a target, even when participants are informed beforehand of the features (e.g., color) of the upcoming distractor. In those studies, however, participants may not have been particularly motivated to recruit attentional processes and try to prevent attentional distraction by upcoming stimuli. In the current study we investigated whether participants could use pre-trial information about the color of an upcoming distractor to prevent themselves from getting distracted by it, when a reward was at stake. Results showed that a performance-contingent reward reduced distraction overall by physically salient stimuli. However, reward did not increase the likelihood that participants would use information about the color of the upcoming distractor to further improve visual search performance. This study highlights the fast and reflexive nature of attentional capture by physically salient distractors, which is difficult to control strategically, even when motivated to do so.

Keywords: attentional capture; physical salience; reward; visual search

Introduction

The ability to control attention is critical for goal-directed behavior. A large amount of information enters the perceptual system, and the cognitive system needs to prioritize that which is relevant. Furthermore, this system needs to flexibly adapt, as the goals of the organism change. For example, when foraging for blueberries the attention system should prioritize small, blue, round objects. Alternatively, when meeting a friend at a train station, the system needs to prioritize people of a certain height with particular facial features.

There is an abundance of experimental evidence that goals and instructed task sets bias the attentional system towards the processing of stimuli that are relevant for achieving current goals (Folk et al., 1992; Yantis, 2000). However, it is also very difficult for individuals to ignore task-irrelevant yet physically salient stimuli that function as distractors in visual search tasks (Theeuwes, 1992, 1994). Physically salient stimuli are those that stand out from other items by virtue of their physical characteristics (such as color or luminance). For example, evidence for attentional capture by physically salient but task-irrelevant stimuli comes from the additional-singleton task (Theeuwes, 1992, 1994), a version of which was used in the current study. In this task participants are required to search for a unique target shape amongst other shapes (e.g., a diamond amongst circles). On some trials all the stimuli are rendered in grey (distractor absent trials), whereas on other trials one of the circles is rendered in color (distractor present trials). Numerous studies have demonstrated that response time (RT) to respond to the target is slowed on distractor present vs. absent trials, despite the fact that color is irrelevant to the task at hand. The implication is that the salient distractor sometimes captures participants' attention, thus slowing search for (and response to) the target. Eye-tracking studies have demonstrated that such attentional capture is fast and reflexive, characterized by fast saccades to the salient stimulus (Theeuwes et al., 2003). Furthermore, the control of attention away from physically salient distractors requires cognitive resources and effort. Evidence for this comes from demonstrations that under working memory load, the physical salience distraction effect (i.e., slower visual search in the presence of salient singleton distractors) is more pronounced (Lavie & de Fockert, 2005; Watson, Pearson, Chow, et al., 2019).

Several studies have investigated whether participants can use information about the spatial location or features (e.g., color) of upcoming distractors to reduce the physical salience distraction effect in visual search – that is, whether prior knowledge can (to some extent at least) inoculate participants against distraction by salient stimuli. There is convincing evidence that *spatial* locations where distractors are likely to appear can be suppressed during visual search, leading to reduced distraction and improved visual search performance when salient distractors appear at expected locations (versus unexpected locations). Some visual search studies manipulated statistical regularities in trial distributions so that participants could learn by experience that distractors were more likely to appear in specific spatial locations than others (Le Pelley et al., 2022; Wang et al., 2019; Wang & Theeuwes, 2018a, 2018b). In other studies, the distractor location was unpredictable on a trial-by-trial basis, but participants were provided with explicit information (in the form of pre-trial cues) as to the probable location of upcoming distractors and could capitalize on this information to suppress attention at that location (Chao, 2010; Munneke et al., 2008; Van der Stigchel & Theeuwes, 2005).

Despite this evidence that participants can use information about upcoming spatial locations of distractors to ignore those locations and improve target search efficiency (whether this is based on experience or is explicitly cued), *feature* suppression of distractors appears to be more complex. On the one hand, participants can eventually reduce attentional capture by physically-salient distractors in visual search tasks

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when the color of the distractor is repeated across consecutive trials (Gaspar & McDonald, 2014; Gaspelin et al., 2019; Gaspelin & Luck, 2018; Vatterott & Vecera, 2012). This suggests that experience with distractor colors leads to the development of a 'distractor rejection template'. Surprisingly however, attentional capture by physically-salient distractors is not significantly reduced when participants are instructed on each trial as to the color of upcoming distractors (Cunningham & Egeth, 2016; Gaspelin et al., 2019; Moher & Egeth, 2012; Moorselaar & Slagter, 2020; Wang & Theeuwes, 2018b). Moher and Egeth (2012) for example, provided participants on each trial with instructions that stated the color of the distractor in the upcoming search display. They reported that participants were *slower* to identify the target on trials where this information was provided, relative to trials with no information. Similar counterintuitive patterns of results (Cunningham & Egeth, 2016; Gaspelin et al., 2019) have been attributed to an ironic "white bear" effect (it being impossible to suppress something which you have been instructed not to think of).

However, an alternative possibility for why prior information may not reduce distraction by salient distractors is that participants may have little motivation to make use of this information. That is, the motivation for participants to use the information about the upcoming trial might play a critical role in determining whether attentional processes will be recruited to prevent attentional distraction by upcoming stimuli – especially given that deployment of the necessary control processes may be cognitively effortful (Lavie & de Fockert, 2005; Watson, Pearson, Chow, et al., 2019). In all the studies mentioned earlier, the distractors were motivationally irrelevant to participants. That is, there was no explicit benefit to participants for utilizing the information about the upcoming distractor information in an attempt to improve their visual search performance. Although their response to the target might be slightly faster as a result, this had no tangible impact on the outcome of the task. This raises the possibility that in circumstances where slower RT has no consequence, participants are not motivated to recruit cognitive control and overcome distraction. Alternatively, when distraction incurs a cost, it seems feasible that participants might be more likely to use information about the upcoming distractor and try to suppress attention to that spatial location or distractor feature.

In the current study, we explored whether participants could use information about upcoming distractor features to reduce distraction by those stimuli, and in particular whether greater evidence of distraction suppression would be observed when a reward was at stake. Participants completed a version of the additional-singleton task (online) where they had to respond to the orientation of the line within a grey diamond (the target). On each trial the target appeared among five grey circles, one of which was colored pink, blue or orange on half the trials (the singleton distractor). To investigate whether knowledge about the upcoming distractor color and the possibility of reward could motivate participants to avoid distraction and locate the target more quickly, each trial began with an information cue. On half of the trials (specific information condition) participants were informed of the color of the upcoming distractor (or notified that no colored distractor would appear). On the other half of trials (general information condition) participants received a notification that the trial was about to begin, but no information was provided about the upcoming distractor (or absence thereof). In addition, participants were given information at the start of each trial as to whether or not they would earn monetary reward for fast and accurate responding on that trial. Crossing the variables of information (specific vs. general) and reward (no reward vs. reward) resulted in four different conditions during the experiment under which the physical salience distraction effect could be examined. In line with previous experiments we did not expect distractor information alone to lead to a reduction in the physical salience distraction effect (Cunningham & Egeth, 2016; Gaspelin et al., 2019; Moher & Egeth, 2012; Moorselaar & Slagter, 2020; Wang & Theeuwes, 2018b). However, we expected the physical salience effect to be reduced in the reward-specific-information condition relative to the reward-general-information condition. That is, we expected participants to use the information about the upcoming distractor color to improve visual search performance on trials where they knew a reward was at stake.

Method

Participants & Apparatus

Participants were recruited from the UNSW School of Psychology and participated for course credit. G*Power analysis indicated that 67 participants would give 80% power to detect a small-to-medium effect size (d_z = 0.35) for the critical t-test comparison of a difference in the physical salience effect in the 'specific information + reward' condition relative to the 'general info + reward' condition. We aimed therefore to test approximately 95 participants, assuming that data from 25-30% of the online sample would be excluded. Ninety-two participants completed the study with 29 excluded (see Results section).

The task was programmed in jsPsych (de Leeuw, 2015) and delivered over the internet to participants to complete in their own time. The task script can be downloaded from https://osf.io/xcbn7/.

Materials

Participants completed an RT version of the additional singleton task (depicted in Figure 1A). Each trial began with an instruction screen that contained either general information that the trial was about to begin or specific information about the distractor type on the upcoming trial (see Figure 1B). This general or specific information was presented in the top 1/3 of the screen in white font (font-size: 50px). On trials where a reward could be earned, "$$" (font-size: 70px) was displayed in green, in the bottom 1/3 of the screen. The information screen was presented for 1500ms followed by a fixation cross for 1000ms and then a 150ms blank screen. The search display was then presented for 1000ms. This display consisted of six shapes (size: 100px × 100px) spaced evenly around an imaginary circle (diameter 400px). Of these shapes, five were circles and one was a diamond (the target). Each circle contained a white line tilted 45° randomly to the left or right. The diamond target contained a line oriented either horizontally or vertically (randomly). On half of the trials, one of the circles (the distractor) was rendered in either blue, orange or pink and all other shapes were grey. Target and distractor location were randomly determined on each trial. Participants responded as quickly as possible to the orientation of the line within the diamond by pressing the ‘C’ key if it was horizontal and the ‘M’ key if it was vertical. Following the response (or after 1000ms timeout) participants saw the feedback screen for 700ms. If it was not a reward trial, participants saw either “Correct”, “Error” or “Too Slow” as appropriate. If it was a reward trial, however, then participants earned a point for every ms that their (correct) RT was faster than 1000ms i.e., a correct response with an RT of 600ms would earn 400 points, with feedback stating “Correct, + 400 points!”. Errors or timeouts earned no points; feedback stated “Too Slow, 0 points” or “Error, 0 points” respectively. The blank screen inter-trial interval that followed was 700, 800 or 900ms (selected at random).

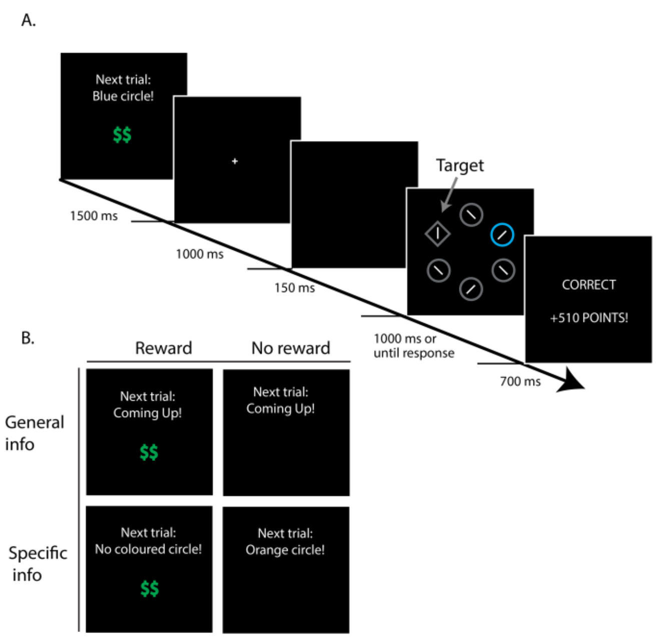

Figure 1: The visual search task **A.** The trial structure **B.** Examples of pre-trial instruction screens. Reward (reward vs. no reward) was crossed with information type. The information provided could be general information that the trial was about to begin, or specific information as to the color of the upcoming distractor (or a notification that there would not be a distractor on distractor-absent trials). Figure not to scale.

Procedure

At the beginning of the experiment all participants received general task instructions to respond to the orientation of the line inside the diamond as quickly and accurately as possible. They then completed a short practice phase with trials that featured a yellow distractor. They were then instructed that on some trials they could earn points for fast and accurate responding and that the 20% of participants with the most points at the end of the task would earn a $15 voucher from the store of their choice. Participants were then informed that trials would begin with information about the upcoming trial type and the possibility of reward. They were told explicitly that the colored circles were there to distract them and that they should use the information at the start of each trial to help them to ignore the colored circles and hence prevent distraction. They were also told that if they could ignore the circles then they could respond faster to the diamond and earn more points (on reward trials). To proceed with the experiment participants had to answer a series of check questions to ensure they understood the different instruction screens and what they meant.

Participants then completed eight blocks of 72 trials with a self-paced break at the end of each block during which they were informed of the total points they had earned so far in the experiment. Each block contained 9 trials from each of eight different conditions, formed by full factorial combination of the factors of distractor presence (distractor present vs absent), reward (reward available vs no reward available), and information type (specific information vs general information). Across the eight blocks of trials (576 trials total), participants thus completed 72 trials of each condition.

At the end of the experiment participants were asked to report their age and gender.

Data Processing & Statistical Analyses

The processed means data for each participant, used in the analyses reported below, are available at: https://osf.io/xcbn7/.

We followed our standard procedures for processing the data (Le Pelley et al., 2022; Watson, Pearson, Most, et al., 2019). Anticipatory responses (RT<150ms) or responses that were too slow (RT>1000ms) were discarded.

Mean error rates and RT on correct trials only were analyzed with repeated measures ANOVA with factors of distractor (present vs. absent) x reward (reward vs. no reward) x information (general vs. specific). Preliminary analyses indicated that adding block to the ANOVA did not alter the pattern of results and thus for simplicity of presentation is not included here.

For planned, more focused comparisons we then calculated the difference in RT and error rates on distractor-present minus distractor-absent trials, separately for each of the four conditions. We used both frequentist and Bayesian two-sided, paired-sample t-tests to compare the effect of general vs. specific information in the no-reward and reward conditions.

Results

Participants

Twenty-nine participants were excluded for having trial exclusions (timeouts or anticipatory RTs) in excess of 20% or for having proportion errors of more than .40. The remaining 63 participants (47 females, 14 males, 2 other) had a mean age of 18.7 years (*SEM:* 0.2 years). The mean percentage of trial exclusions was 3.6% (*SEM:* 0.4%) and mean proportion errors was .13 (*SEM:* 0.01).

Visual Search Performance: Correct RTs

Responses were faster on distractor absent trials than distractor present trials (main effect of distractor type: $F(1,62) = 149.2$ $p < .001$, $\eta_p^2 = 0.7$), as visualized in Figure 2A. Responses were also faster on rewarded trials than unrewarded trials, $F(1,62) = 51.4$, $p < .001$, $\eta_p^2 = 0.5$) but the main effect of information type was not significant $F<1$, $p = .732$, $\eta_p^2 = 0.002$. Reward reduced the size of the physical salience effect with an interaction between distractor and reward type (see Figure 2C), $F(1,62) = 4.8$, $p = .033$, $\eta_p^2 = 0.07$ but there were no further significant effects: Fs<2.9, ps>.094. η_p^2s <0.045.

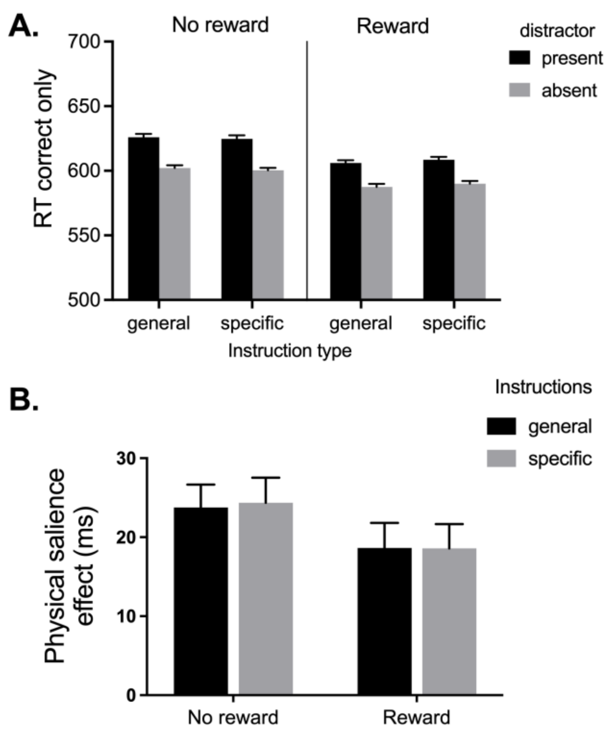

Figure 2: RT on correct trials in the visual search task. **A.** Mean RT across all conditions. **B.** The physical salience effect (mean RT on distractor-present trials minus distractor-absent trials). Error bars represent the within-subject SEM, calculated using the Cousineau method (2005) with Morey correction (Morey, 2008).

As can be seen in Figure 2B, the effect of information (i.e. difference in the physical salience RT effect between the specific and general information conditions) was not statistically significant in the no-reward condition $t(62) = 0.16$, $p = .873$, $d_z = 0.02$ with moderate support for the null hypothesis, $BF_{01} = 10.0$ Critically, this comparison was also not significant in the reward condition $t(62) = 0.02$, $p = .988$, $d_z < 0.01$, with moderate support for the null, $BF_{01} = 10.1$.

Visual Search Performance: Errors

As can be seen in Figure 3A, participants made more errors on distractor present trials than distractor absent trials as indicated by a main effect of distractor type: $F(1,62) = 12.5$, $p < .001$, $\eta_p^2 = 0.17$. They also made significantly more errors on specific instruction trials than general instruction trials, $F(1,62) = 8.5$, $p = .005$, $\eta_p^2 = 0.12$. The interaction between distractor type and instruction failed to reach significance, $F(1,62) = 3.5$, $p = 0.066$, $\eta_p^2 = 0.05$. The main effect of reward was not significant: F<1, $p = .535$, $\eta_p^2 <0.01$, nor were there any further significant interactions, Fs<2.4, ps>.124. η_p^2s <0.04.

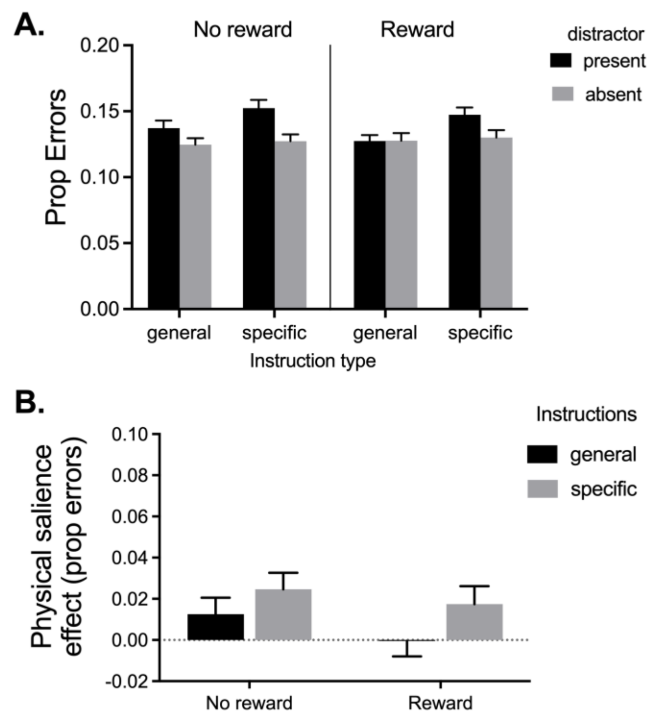

Figure 3: Proportion of errors in the visual search task. **A.** Mean proportion of errors across all conditions. **B.** The physical salience effect (mean proportion of errors on distractor-present trials minus distractor-absent trials). Error bars represent the within-subject SEM, calculated using the Cousineau method (2005) with Morey correction (Morey, 2008).

When examining differences in error rates, the paired comparison revealed a non-significant effect of information (specific vs. general) on the physical salience effect in the no-reward condition $t(62) = 1.25$, $p = .215$, $d_z = 0.16$ with anecdotal support for the null hypothesis, $BF_{01} = 4.7$, see Figure 3B. This comparison was also not significant in the reward condition $t(62) = 1.73$, $p = .089$, $d_z = .47$, although with inconclusive evidence in favor of the null, $BF_{01} = 2.4$.

Discussion

In the current experiment we provided participants with information at the start of each trial about the color of the upcoming distractor and the possibility of reward for fast and accurate responding. In line with previous research we did not expect participants to use the information about the upcoming distractor color to improve their visual search performance, on trials where no reward was available (Cunningham & Egeth, 2016; Gaspelin et al., 2019; Moher & Egeth, 2012; Moorselaar & Slagter, 2020; Wang & Theeuwes, 2018b). However, when reward was at stake, we expected that participants would be able to suppress the distractor color and respond as quickly as possible to the diamond target, thus reducing the physical salience distraction effect. Contrary to our predictions however, the physical salience distraction effect was not significantly reduced on reward trials when participants were provided with specific information relative to when they were provided with general information that the trial was about to begin.

These findings suggest that participants are not able to voluntarily prevent attentional capture by physically salient distractors, even when there is a tangible benefit to doing so. This is not to say that the attentional system lacks such a mechanism to suppress features of expected task-irrelevant distractors. A number of studies have demonstrated that when distractor colors are repeated over trials, the magnitude of the physical salience effect reduces for these repeated colors relative to occasional rare/unexpected distractor colors (Cunningham & Egeth, 2016; Gaspelin & Luck, 2018; Vatterott & Vecera, 2012). The implication is that participants can learn to ignore distractor features as a consequence of repeated experience. That is, suppression of distractors on the basis of color can be conditioned, but the current data suggest that it cannot be actioned voluntarily. The shifts of attention towards the physically salient distractors in the additional-singleton task are likely occurring rapidly and reflexively and thus not able to be controlled by top-down attentional processes (Godijn & Theeuwes, 2002).

An alternative explanation for the pattern of results is that participants simply ignored the pre-trial information or that the magnitude of the reward was not sufficient to motivate participants to try and improve performance. However, a clear effect of the reward manipulation was seen in the RT data – participants were faster at responding on trials where a reward was at stake (without a corresponding loss in accuracy) and the physical salience effect was reduced on reward trials (when collapsed across the information conditions). This finding is suggestive of a general motivational effect whereby participants are more engaged with the task and are trying to respond faster overall (Chelazzi et al., 2013; Pessoa & Engelmann, 2010), rather than an effect that is specific to feature suppression.

As a further indication that participants were not simply ignoring pre-trial information, an effect of instruction type was seen in the error data. Participants made slightly more errors on specific-information trials relative to general-information trials. This suggests that participants were reading the pre-trial instructions and attempting to act on them but were not able to capitalize on information about the upcoming distractor to improve performance.

The finding that error rates slightly *increased* following specific information about the upcoming distractor type is reminiscent of the 'white bear' effect. This refers to experiments showing that participants who were instructed to suppress thoughts of a white bear reported thinking of it more frequently than participants who had not been instructed to suppress any thoughts (Wegner et al., 1987). Under this account, being instructed to ignore a colored distractor leads paradoxically to increased distraction by that stimulus (Cunningham & Egeth, 2016). It should be noted that while it appears in Figure 3A that the increased errors on specific-instruction trials were largely observed in the distractor-present rather than distractor-absent condition, we did not find a statistically significant interaction between distractor type and information type in the main ANOVA analysis. The white bear effect is therefore largely anecdotal in our study, because a white bear effect cannot occur on distractor-absent trials. The participant is not being instructed to suppress anything on distractor-absent trials, so increased error rates following distractor-absent instructions would be suggestive of a general performance effect, whereby participants might become overconfident and simply make more errors.

In summary the present study confirmed that even when it would be beneficial to do so, participants could not use information about the upcoming distractor color to suppress attention to that feature and improve visual search performance. Reward led to a reduced physical salience effect, but this did not differ significantly across information conditions. These results demonstrate the fast and reflexive nature of attentional capture by physically salient distractors, which is difficult to control strategically.

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