Acknowledgements

We thank Anxu Wang for assisting with data acquisition.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was partly funded by NSF [grant number IIS-1162067], [grant number BCS-1056730].

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Rewards shape attentional search modes

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Visual attention can be configured for specific stimulus features (feature search mode) or it can be non-specifically set for salient pop-outs (singleton detection mode). Additionally, monetary rewards have been shown to bias attention toward specific features, but it is unknown whether secondary reinforcers (images of US$) can shape global attention via search modes. In a between-

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group study, we trained participants to value one search mode over the other. In a testing phase, a salient distractor captured the attention of the value-singleton group; however, the value feature group was completely unaffected. This suggests that rewards automatically bias global attention mechanisms and potentially mediate the handoff between stimulus-driven and goal-directed attentional control.

ARTICLE HISTORY Received 19 July 2015; Accepted 28 August 2015

KEYWORDS Rewards; Visual attention; Search modes; Attentional control

When conducting a visual search, humans can adopt at least two different search modes. The so-called *singleton search mode* is primarily stimulus-driven. For example, when subjects search for a pop-out target, singleton distractors usually capture attention (Theeuwes, 1992). In contrast, *feature search mode* is primarily goal-directed. If a subject is in feature search mode and searches for a red target, then a template-matching red distractor, but not a green distractor, will capture the subjects' attention (Folk, Leber, & Egeth, 2002). When given the option, subjects often default to the easier singleton search mode (Kawahara, 2010). We wondered if we could use implicit reward stimuli (US bill images without actual payment) to incentivize subjects to use the more difficult feature search mode.

Methods

The experiment involved a training phase with rewards and a testing phase with a critical distractor. Twenty-four subjects completed six alternating train-test blocks of 72 trials (i.e., ABABAB design). Stimulus displays for the two phases are illustrated in Figure 1(a). Training consisted of two types of trials—feature search displays and singleton search displays. An equal number of these displays were randomly intermixed within each training block. Subjects searched for a line segment contained within a shape (circle, diamond, hexagon, square, pentagon, or heptagon) and reported its orientation (vertical or horizontal). There were six shapes presented on every trial. On singleton search trials, the target always appeared within a unique shape (e.g., diamond amongst squares). On feature search trials, the target was always inside a circle and the remaining shapes were heterogeneous.

During the training phase only, images of US bills appeared after correct trial performance. Twelve subjects, hereafter referred to as the value-singleton group, were highly rewarded (image of US$20 bill shown) after singleton search trials and lowly rewarded (image of US$1 bill shown) after feature

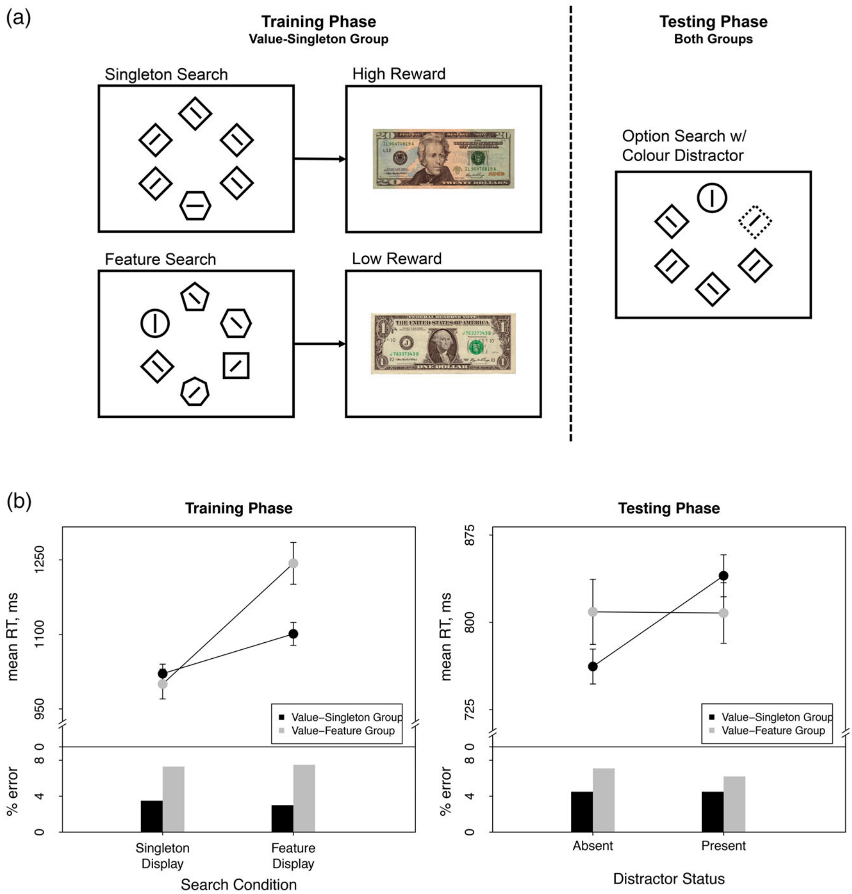

Figure 1. (a) Training and testing phase schematics. Search displays were differentially reinforced between two groups. The figure depicts the contingency for the value-singleton group. The reward contingency was reversed for the value-feature group (not depicted). The testing phase was identical for both groups. The dashed line depicts a colour singleton distractor that was present on 50% of the testing trials. (b) Mean RT and error rates. Errors bars represent 95% within-subject confidence intervals (Cousineau & O'Brien, 2014; Loftus & Masson, 1994).

search trials. This contingency was reversed for the other 12 subjects, hereafter referred to as the value-feature group. Critically, all subjects knew in advance they were to receive a fixed amount of course credit and *zero* monetary payment as compensation.

The testing phase was identical to the singleton search condition of the training phase except the target was always a circle and a single non-target shape occasionally appeared (50%) as a uniquely coloured distractor (e.g., red square amongst yellow squares and yellow circle). The colour singleton was poised to distract attention away from the target via stimulus-driven attentional capture.

Subjects engaged in singleton search mode are non-specifically looking for the different item and thus are particularly prone to salient distractors. However, subjects engaged in feature search mode are looking for a specific shape (circle) and thus should be configured to easily avoid colour-induced distraction. Therefore, we hypothesized that if rewards bias search mode behaviour, then participants in the value-singleton group should show evidence of greater distraction in the testing phase.

Results

Data trimming

Incorrect trials and response latencies ±2.5 SDs of the mean were removed from analysis (this eliminated 6.5% of the data).

Training phase

Mean correct response times (RTs) for training trials were separately computed for singleton and feature search displays (see Figure 1(b)). These values were entered into a mixed model repeated-measures ANOVA. Feature search displays produced longer RTs ($M = 1172$ ms, SEM = 49.0 ms) compared to singleton search displays ($M = 1010$ ms, SEM = 34.6 ms, $F(1,22) = 36.81$, $p < .001$, $\eta_p^2 = .63$). The between-group effect was not significant, $F(1,22) = .56$, $p = .46$, $\eta_p^2 = .03$. Importantly however, the group x search display interaction was significant, $F(1,22) = 9.47$, $p = .006$, $\eta_p^2 = .30$. Follow-up analyses revealed that the value-feature group showed a greater RT difference between search conditions (243 ms for value-feature, $t(11) = 5.32$, $p < .001$, compared to 80 ms for the value-singleton group, $t(11) = 2.91$, $p = .01$). There was no significant effect for an analogous analysis of mean error rates, *p*s > .60.

Testing phase

Mean correct-response RTs for testing trials were computed separately for distractor present and absent trials (see Figure 1(b)). These values were entered into a mixed model repeated-measures ANOVA. This analysis revealed a main effect of distractor status $F(1,22) = 35.60$, $p < .001$, $\eta_p^2 = .62$. Distractor present displays ($M = 824$ ms, SEM = 31.4 ms) produced longer RT compared to distractor absent displays ($M = 786$ ms, SEM = 31.3 ms). The between-group effect was not significant, $F(1,22) = .02$, $p = .90$, $\eta_p^2 = .001$. Similar to training, we also observed a significant group x distraction interaction, $F(1,22) = 36.81$, $p < .001$, $\eta_p^2 = .63$. Follow-up analyses revealed that the value-singleton group showed a significant distraction effect of 77 ms, $t(11) = 7.31$, $p < .001$, whereas the value-feature group exhibited no distraction ($M = -1$

ms, $t(11) = .089$, $p = .93$).There was no significant effect for an analogous analysis of mean error rates, $ps > .48$.

Discussion

In this experiment, rewards delivered during a training phase effectively biased attentional control in a subsequent testing phase. When subjects were highly rewarded after completing singleton search, they apparently persisted in singleton search mode. In contrast, when subjects were highly rewarded after completing feature search, they persisted in feature search mode. Critical group interactions were observed in training *and* testing phases. Importantly, the only manipulated difference between the groups was the treatment of reward contingency. Therefore, we conclude that attentional control settings automatically adjust to reflect fluctuations in value-based environmental contingencies. Furthermore, rewards effectively mediate the bridge between stimulus-driven and goal-directed control settings. These findings agree with contemporary thoughts on attentional control (Vecera, Cosman, Vatterott, & Roper, 2014) and reward-based attention (Anderson, 2013; Awh, Belopolsky, & Theeuwes, 2012).

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