Rewards shape attentional search modes

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Disclosure Statement

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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 (Kawhara, 2010). We wondered if we could use implicit reward stimuli (U.S. 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 1a. 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.
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During the training phase only, images of U.S. bills appeared after correct trial performance. Twelve subjects, hereafter referred to as the value-singleton group, were highly rewarded (image of $20 bill shown) after singleton search trials and lowly rewarded (image of $1 bill shown) after feature search trials. This contingency was reversed for the other twelve 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 colored distractor (e.g., red square amongst yellow squares and yellow circle). The color 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 color-induced distraction. Therefore, we hypothesized that if rewards bias search mode behavior, 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 1b). These values were entered into a mixed model repeated-measures ANOVA. Feature search displays produced longer RT ($M = 1,172$ ms, $SEM = 49.0$ ms) compared to singleton search displays ($M = 1,010$ 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, $ps > .60$.

**Testing Phase**

Mean correct RTs for testing trials were separately computed for distractor present and absent trials (see Figure 1b). 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, $t(11) = .089$, $p = .93$).
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$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 et al., 2014) and reward-based attention (Awh, Belopolsky, & Theeuwes, 2012; Anderson 2013).
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References


Figure Caption

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 color 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).
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Figure 1

a

Training Phase
Value-Singleton Group

Singleton Search
High Reward

Feature Search
Low Reward

Testing Phase
Both Groups

Option Search w/
Color Distractor

b

Training Phase

Testing Phase

mean RT, ms

% error

mean RT, ms

% error

Search Condition

Distractor Status

Singleton Display
Feature Display

Absent
Present

Value-Singleton Group
Value-Feature Group

Value-Singleton Group
Value-Feature Group