Reward is a powerful motivator that underlies many human behaviors and cognitive processes (**Madan, 201**7). One area in which reward has become increasingly relevant is attention. Attention has long been argued to be driven by top-down and bottom-up process. Yet, a growing body of work has placed prior selection history, which includes selection driven by reward, as a third competitor involved in selective attention (**Awh, Belopolsky & Theeuwes, 2012; Theeuwes, 2010; Theeuwes, 2018**). Through a process called value-directed attentional capture (VDAC), learned stimulus-reward associations have been shown to automatically modulate attention such that reward-associated stimuli may receive greater attentional priority in spite of any task-related goals of an observer (**Anderson, Laurent & Yantis, 2011**). Critically, VDAC may have unintended downstream effects on other related cognitive processes including memory.

Value-driven attention capture was first identified by **Anderson et al., (2011**). Participants were trained using a visual search task to associate one of two target colors with a higher probability of receiving the greater of two reward amounts. Correct responses to a high-value colored target would yield an 80% chance of a high reward (5¢) and a 20% change of a low reward (1¢) whereas this contingency was revered for low value-color. In a subsequent singleton detection task, the high- and low-rewarded colors from the training phase were presented as a distractor. Trials with high-value distractors led to slower response times compared to trials with low-value distractors or distractors without any previously associated value. This suggests that the magnitude of reward associated with a stimulus changes how strongly that stimulus captures attention.

The effects of VDAC can persist from days to months after training (**Anderson et al., 2013; Della Libera & Chelazzi, 2006, 2009**) and in contexts in which attending to reward-associated stimuli incurs penalties, as demonstrated with oculomotor tasks (**Anderson, Laurent, & Yantis, 2012; Pearson, Donkin, Tran, Most & Le Pelley, 2015; Theeuwes & Belopolsky, 2012).** Furthermore, reward associations do not need to be relevant to the training task. **Mine and Saiki (2015**) showed that training color-reward associations on an Eriksen flanker task where colored stimulus is irrelevant or even the to-be-ignored element still results in VDAC which has implications on how effortlessly reward associations may form. Aside from capturing attention as a distractor, reward has also been used to focus attention on target stimuli containing rewarded stimulus features against other possible distractors (**Walsh, Carmel, Harper, Bolitho & Grimshaw, 2020; Schwartz, Siegel & Castel, 2020**). Altogether, VDAC has been shown to be long-lasting, automatic, and resistant to cognitive control.

Considering these strong effects of reward on attention, a natural extension of the topic would be whether reward has similar effects on processes related to attention such as working memory. It is recognized that working memory shares common resources and is extensively involved with attention **(Chunn, 2011; Kyonaga & Egner, 2012; Chun & Turk-Browne, 2007).** A particularly relevant function of attention includes selecting or prioritizing what information kept represented in working memory **(Oberauer, 2019)**. Thus, the automatic biasing of attention towards rewarded stimuli may enhance memory of those items at the cost of reduced attention and memory capacity for unrewarded stimuli.

To this end, a number of studies have investigated whether reward influences visual working memory with mixed results. In a study by **Gong and Li (2014),** participants completed a change blindness task featuring reward-associated colors before and after engaging in the value-training procedure used by **Anderson et al., (2011).** The authors found enhanced discriminability in the change-blindness task post-training compared to pre-training. Likewise, **Infanti, Hickey and Turatto (2015)** had participants complete a partial report visual working memory task spanning retention times of 50 ms and 800 ms following the training procedure of **Anderson et al., (2011)**. While they failed to find similar enhancements to accuracy as **Gong and Li (2014**), they did find an interference effect when reward-associated stimuli were presented in proximity to the memory target across iconic and visual working memory spans.

In explaining these findings, some have suggested reward may act on visual working memory by speeding visual processing (**O’Brien & Raymond, 2012**) or increasing working memory capacity (**Kawasaki, Yamaguchi, 2013**). Others have suggested reward may shift attentional allocation between items as a trade-off (**Morey, Morey & Rouder, 2011).** One study by **Sandry & Ricker** (2020) investigated whether the orientation of attention towards a list item might increase maintenance of that item in visual working memory at the expense of other items. Participants were presented three sequential shapes where one item may be rendered in red indicating increased rewards for that trial and given a 2-alternative forced choice recognition task. While there was no effect on accuracy, response times to reward-colored items was faster which the authors concluded was evidence that prioritized items were being better maintained in working memory, hence the faster retrieval times.

However, there are a number of gaps left by the study. As with other studies, only accuracy is reported which fails to capture whether any apparent memory enhancement is simply the result of a response bias shift (**Bowen, Marchesi & Kensinger, 2020**). Furthermore, unlike prior studies using separate training and test phases, participants in **Sandry & Ricker’s (2020)** experiment were rewarded per trial, limiting any interpretations about the long-term effects of reward in this task.

The aim of the current study was to characterize the impact of reward on working memory using analyses of response time, discriminability, and response bias. We combined the value-learning procedure of **Anderson et al. (2011**) with a visual Intrworking memory task similar to **Sandry and Ricker (2015**). In the learning phase, two reward amounts (high and low) were associated with two target colors (red and green). In the test phase, participants were presented with a series of three characters followed by a test probe that asked whether the probed item was a new or old item. In some lists, one item was be presented in a high- or low-value color. In lists with a colored item, the probe could be for the colored item, or it could be for a non-colored item. This experiment expands on **Sandry and Ricker’s (2015**) study in a few ways. By ensuring rewards are only delivered in a previous training phase and not in the test phase, we ensure parity between our findings and those of VDAC literature. Furthermore, by using an old/new judgement task, we can further examine effects on discriminability and criterion placement, both for rewarded items and for unrewarded items in proximity to a rewarded item.

We propose two hypotheses. First, if reward enhances attention in a way that boosts working memory representation, we expect to see faster response times and/or greater discriminability for items rendered in a high reward color, with some costs to non-colored items. Alternatively, if reward-association does not boost memory representation, but instead simply leads to strategic shifts in response bias, we expect to see a trend between increasing reward association and response bias shift. Bowen et al., (2020) found that increasing reward magnitude led to a liberal criterion shift, or more willingness to endorse an item as old, which would concur with other studies finding improvements to hit rates. Thus, we predict a similar relation between reward magnitude and response bias.

Methods

Participants

Seventy students (47 female, 1 other, 20 male) from the University of Illinois at Urbana-Champaign participated in the online study in exchange for course credit. Mean age was 19.75 (ranging from 19 to 22) Data from two participants were omitted due to recording errors. We selected our sample size according to prior effect sizes (Coehn’s *d* = 0.3) found from a similar study by **Sandry, Schwark, and MacDonald (2014**). All participants had normal or corrected-to-normal vision, normal color vision.

Materials

The study was run online on a university server. Stimuli were created with the JsPsych 6.2.0 library in Javascript **(de Leeuw, 2015)**. While we could not control for individual screen differences, participants with monitor dimensions below 480p x 480p were excluded from running the experiment.

Procedure

The experiment took about an hour to complete and was comprised of two parts.

Training Task.

In the training phase, participants completed a visual search task in which they identified the orientation of a horizontal or vertical bar position within a green or red target circle. Each trial began with a fixation cross lasting between 400 to 600 ms. The search display was presented for 1000 ms or until participant response and consisted of 6 black lines each contained within a uniquely colored circle. The stimuli were arranged in an equidistant circle around the fixation cross as shown in **figure X**. Five of the six lines were randomly orientated in a diagonal direction (+45° or -45°) and each was encompassed by a non-target colored circle (cyan, blueviolet, black, magenta, and gold; color are reported according to html color names). The target line was oriented horizontally or vertically and was defined by a green or red circle and only one target was presented in each trial. The target was equally likely to appear in any of the six positions. Participants were instructed to search for a red of green target circle and report as quickly and as accurately as possible the orientation of the line inside the circle by pressing “Z” for horizontal or “M” for vertical. After the search display was presented, participants received feedback using a point display for 1500 ms. Participants received “+2 points” or “+10 points” for correct responses and “Miss” for wrong or late responses along with a running total of how many points they have earned.

For each participant, one of the two target colors (red and green) were randomly assigned as the high value color, and the other as the low value color. Correct responses to high-value targets had an 80% chance of receiving a higher reward amount of 10 points and a 20% chance of receiving a lower reward amount of 2 points (and vice versa for low-value targets). Thus, the training phase would imbue one color with a high value and the other color with low value.

Participants completed 10 practice trials with the option to repeat before moving to the experimental trials. Participants completed 200 experimental trials divided in 4 blocks. In-between blocks, participants were given a 30-second break screen that reported overall accuracy and the total number of points they have earned.

Test phase.

In the test phase, participants were tasked with remembering visual stimuli in an old/new recognition task. Each trial began with a fixation cross lasting between 400 to 600 ms. Then, three different characters were sequentially presented for 500 ms each followed by a 500 ms mask as shown in **figure X**. We used a set of 90 unique characters from taken from the Brussles Artificial Character Sets (**Vidal, Content, Chetail, 2017**) which are a set of standardized characters that emulate features of various languages without being identifiable to participants. Within each trial, characters were randomly sampled without replacement from the total stimulus set, but characters could be repeated between trials. Characters were presented in black but on some trials, one character would be presented in red or green corresponding to the high- and low-value colors from the training phase. We refer to these items as high-rewarded items and low-rewarded items, but it should be noted that participants did not receive any rewards in this phase, so the reward color has no bearing on the task.

To maximize the number of critical trials, we adjusted the proportion of old vs. new trials and the ratio of low- high- and no-reward trials. Across 200 experimental trials, we used a 3:2 ratio between old and new trials (120 old: 80 new). For reward colors, we used a 3:3:2 ratio between low-, high-, and no-reward trials (75 high-value: 75 low-value: 50 no-reward:). For old trials, there were an equal proportion of targets in the 1st, 2nd, and 3rd serial positions. For color trials, there were also an equal proportion of colored items in the 1st, 2nd, and 3rd serial positions. (*needs review for clarification – talk about proportion of trials or the actual number of trials for each category and combination*)

After the three to-be-remembered items were presented, a test item was presented for 2500 ms or until participant response. Participants were prompted to press “Z” if the test item was an old item previously presented in the list or press “M” if the test item was a new item that was not presented in the list. After each response, feedback was displayed for 1500 ms with “Correct” for correct responses or “Miss” for wrong or late responses. However, unlike the training phase, participants did not receive any points. Therefore, any the color of any list items were no longer relevant in this phase.

Participants completed 10 practice trials with the option to repeat before moving to the experimental trials. Participants completed 200 experimental trials divided in 4 blocks. In-between blocks, participants were given a 30-second break screen that reported overall accuracy.

Posttest questionnaire.

Following completion of the experiment, participants responded to a brief questionnaire to evaluate whether they were aware of the reward contingency in the learning phase and whether they used any particular strategy on the visual working memory task. We first asked if participants were aware that the color of targets in the learning phase was associated with the rewards they received on any given trial. Next, we presented participants with a list of 10 working memory strategies adapted from **Morrison, Rosenbaum, Fair, and Chein (2016)** and asked which strategies they used. Participants were free to select any number of the strategies listed.

Results in progress

Training Phase

RT

Accuracy

Test Phase

RT

Hit Rate

False Alarm Rate

Discriminability

Criterion

10:30 – 12 12:30 – 1:30