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Follow the Money: The Influence of Reward on Attention in Cross-Dimensional Contexts

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Abstract

Previous studies have shown that stimuli associated with rewards can capture attention when presented as a distractor in follow-up tasks, indicated by slower response times to a target. This occurs even as those stimuli are no longer associated with rewards, and stimuli with higher levels of reward generate slower responses. The purpose of the current experiment was to explore the extent to which this effect, known as value-driven attentional capture, can translate into additional contexts. Specifically, we tested whether value-driven attentional capture would persist even when participants were engaged in a non-singleton search task, which diverges from most of the traditional research. Additionally, we attempted to determine whether attentional capture for color-based reward distractors would be enhanced if participants were given a task where they had to look for a target based on color, which should weight the rewarded color dimension, compared to shape. Results indicate that value-driven attentional capture was not present in the more complex test phase, possibly as a result of the more complex search array or the presence of cues indicating the target. Future research should continue to explore whether value-driven attentional capture is generalizable to more complex tasks.

Introduction

The Organization of Attention

Across the course of an average day, humans are faced with a constant bombardment of visual stimuli and information. And yet, most people tend to persist without being overburdened by this deluge, and that is thanks to the mental process of attention. Attention allows one to narrow the scope and reach of their focus. Key features of attention include a limited capacity to process what is in front of us and the ability to tune out information selectively (Desimone & Duncan, 1995). At first glance, these might seem like cumbersome limitations, but these features are what allow us to get through the flood of information we encounter. Even if we were able to attend to all the information presented to us, our brains wouldn't be able to process and appropriately respond to it, making some filtering necessary. As a result, this implies that there must be some order or hierarchy to the information that is attended, leading to competition among stimuli (Duncan, 1984; Posner & Petersen, 1990).

Competing theories exist as to the nature of this organization, with two main types of attention emerging from the field (Desimone & Duncan, 1995; Anderson, 2013). One of these is bottom-up attention, also known as stimulus-driven or exogenous attention. This phenomenon occurs as a result of the salience of a given stimulus, capturing our attention and leading to involuntary eye movements towards the stimulus. In terms of evolution, this would be necessary to spot a predator leaping out of the bushes, or a surprise punch being thrown. Another example would be trying to avoid a deer that has jumped in front of your car while driving. In addition to stimuli that captures our attention involuntarily, humans also have goals and plans that influence both their behavior and their attention. Directing attention based on goals is known as top-down attention, otherwise referred to as goal-driven or endogenous attention. It would prove useful for ancient humans looking for red berries to eat amongst the bushes, and today would help someone in trying to find their best friend at a party. It attunes us toward stimuli that are relevant to our current objectives (Anderson, 2013).

While some see top-down and bottom-up attention as two completely different modes with an impassable divide between them, others have done work connecting the two, indicating that people make use of both systems in everyday life. Connor, Egeth, and Yantis (2004) review research done on monkeys, finding that top-down attention can modulate and even override bottom-up attention in some cases. In search tasks, neural responses to distractor color singletons (stimuli that stand out from the rest of the array based on a single feature, in this case color) were stronger when doing color search tasks rather than shape search tasks, indicating that the overall goals of the task can alter attention. Additional work creating attentional models found that models that incorporated knowledge of a visual scene into search performed better than those that relied solely on visual salience, indicating that top-down attention can work with bottom-up attention (Navalpakkam & Itti, 2006).

Reward and Attention

While this goal-salience dichotomy has been accepted as a good description of attentional systems, others argue that they do not properly explain all situations in which attention is required and deployed (Anderson, 2013). We can attend to things that are not physically salient and are not a direct part of our current goals. One possible explanation for this is that people will pay special attention to stimuli that are associated with rewards.

Research has shown that reward-learning can aid and increase efficiency in search tasks. Work done by Kiss, Driver, and Eimer (2009) using electroencephalogram (EEG) analysis found increased N2pc signals when targets were highly rewarded compared to targets that were associated with lower rewards. This indicates that reward associations can be used to enhance top-down attention. In one study, participants were completing the Stroop task, an oft-used experiment where participants are presented with the names of words in a font that is a different color from the word itself and are tasked with saying the font color (i.e. the word “red” presented in blue font). In a modified version of this task, participants responded more quickly to colors that were associated with reward than to nonrewarded colors (Krebs, Boehler, & Woldorff, 2010). Additionally, reward can serve as a priming effect for stimuli between trials, where participants respond more quickly to stimuli that had just been associated with high rewards on the preceding trial (Della Libera & Chelazzi, 2006).

Value-Driven Attentional Capture

Another example of reward’s influence on attention, and the focus of this paper, is in a phenomenon known as value-driven attentional capture. First explored by Anderson, Laurent and Yantis (2011), value-driven attentional capture describes how previously rewarded stimuli can capture attention as distractors in follow-up tasks, even when the stimuli are no longer associated with reward and are irrelevant to the task at hand. While previous research indicated how reward could modulate attention in the moment, this indicates that rewarded associations can linger in attentional priority maps for some time after, and importantly it is dependent on the level of reward received. The experiment was split into two parts: a training phase and a test phase (Anderson, Laurent, & Yantis 2011). In the training phase, participants were tasked with looking at arrays of colored circles, each containing a straight line. Participants were told to look for the one circle containing a vertical or horizontal line (the rest were diagonal) and to identify it. After each correct trial participants received a small reward. The target was always within a red or green circle, and unbeknownst to the participant one of those target colors was associated with high rewards (red) or low rewards (green), with reward/color counterbalanced across participants. In the test phase, participants were still tasked with identifying the vertical or horizontal line, but in this portion the target was always the unique shape in the array, such as a diamond among circles. On some trials, the previously rewarded stimuli from the training phase – red and green items – would appear as a distractor in the search array. Importantly, these items were not relevant to the task and were no longer associated with reward, meaning that any attention directed towards them would not be based on top-down or bottom-up attentional models. Results found that reaction times were slowed when a high-reward distractor was present, indicating that reward associations can capture attention and that this is contingent upon the amount rewarded.

In a separate experimental paradigm, similar results were found, indicating that stimuli associated with higher rewards will distract participants to a stronger degree than low reward stimuli (Munneke, Hoppenbrouwers, & Theeuwes, 2015). Additionally, this work found that these effects remain even when top-down attention is deployed, and the target location is already cued, indicating that value-driven attentional capture may be independent of endogenous attention to some degree. However, this does not imply that there is no interplay between the different types of attention. In one experiment, participants were incentivized to look away from locations with reward-associated stimuli by deploying goal-driven attention to a different location. Participants did so, but only over longer periods of time, indicating that value-driven attentional capture can be overcome by voluntary control, but not immediately (Preciado, Munneke, & Theeuwes, 2017).

Research done on value-driven attentional capture and its neural correlates has found that there seems to be a value-driven attention network of the brain, including the caudate tail (part of the basal ganglia), the lateral occipital complex, the intraparietal sulcus, and the early visual cortex (Anderson, 2017). These areas of the brain showed higher levels of activation following high-reward feedback compared to low-reward feedback, in a task similar to Anderson, Laurent & Yantis (2011).

Beyond simply introducing a new dimension to the previous attentional dichotomy, value-driven attentional capture has real-world implications. If reward associations can linger even beyond the context in which the stimuli were rewarded, it can have consequences for our behavior, especially in today's increasingly gamified and reward-driven society. This effect could possibly help explain why phones can prove so distracting – the constant deluge of notifications and alerts flashing across our screen may be associated with prior reward that distracts us from other work. Additionally, this could possibly help explain part of the problem surrounding something like gambling addiction, or how casinos continue to entice customers. Constant reward associations can capture our attention and cause us to alter our behavioral patterns while distracting us from more essential tasks. However, much of the work done in this field has only used simple stimuli, so further research is required before concrete associations with everyday life can be made. Work using more complex, realistic stimuli was done by Hickey and Peelen (2017) by presenting participants with city and environmental landscapes. By analyzing functional magnetic resonance imaging (fMRI) data, they found that, similarly to the previous research, highly rewarded stimuli led to enhanced representations of these target categories, while non-rewarded categories had reduced representations. This impacted their behavior in subsequent trials and shows that there is some external validity to this work and that attentional capture may translate to more realistic contexts.

The Present Study

In the years since Anderson Laurent and Yantis's 2011 paper first introduced the concept of value-driven attentional capture, further research has been conducted to assess the contexts in which this phenomenon is enhanced, reduced, or remains constant. In a follow-up study Anderson, Laurent, and Yantis (2013) found that even when participants are rewarded in the test phase, the previously rewarded stimuli, now distractors, still influence performance. Interestingly, the results indicated that this distraction effect was strongest when current and recent rewards were both high, regardless of the color distractor. This would seem to be counterintuitive, since participants should have the strongest incentive to not be distracted when potential rewards at hand are at their peak, yet the distraction effect is enhanced. One possible explanation for this is that reward associations are maintained via similar systems that predict future reward, and that when this system is at its highest it also leads to the highest activation of the previous awards. These findings and others demonstrate that the field of value-driven attentional capture still has room for growth, and future research would do well to identify the contexts in which it manifests itself.

While the field of value-driven attentional capture has expanded in the ensuing years, one major caveat in the literature remains: much of the work follows the experimental paradigm first established by Anderson, Laurent, & Yantis (2011). While some researchers have branched off and devised unique experimental tasks, a large body of research still involves creating reward-stimuli associations based on color and then searching for the unique shape in the array, in what is known as a singleton search task. That so much of this research has involved singleton search may overstate the prevalence of value-driven attentional capture. Previous research found that irrelevant but salient distractors would consistently capture attention in search tasks for specific targets (Theeuwes 1992). Theeuwes hypothesized that this meant stimulus-driven attentional capture would always override the effects of goal-driven attention and lead to attentional capture. However, Bacon and Egeth (1994) countered that this may only occur when participants are engaged in singleton search tasks. Since participants are engaged in search for a unique object, other unique objects based on salience would always capture attention. They hypothesized that this effect would be diminished when participants were looking for a target more broadly. They defined this approach as feature search mode, and argued that, compared to singleton search mode, unique distractors would not capture attention. To test this, they first recreated the results of Theeuwes (1992) by tasking participants with looking for a shape singleton (a circle among diamonds). They found that a uniquely colored diamond would consistently capture participant attention. In following experiments, they structured the arrays so that singleton search mode would be impossible, forcing participants to utilize feature search mode. In one experiment, they did this by populating the search array with multiple targets, and in the second array they caused it by adding multiple shape types to the array. In both experiments, the singleton distractor had no effect on attention, giving credence to the idea that it may only be effective in singleton search tasks. While this research looked at physically distinct singleton distractors, it is possible the same effect could occur for reward-associated distractors. Our research plans to test this by comparing singleton search results to a search task featuring an array composed entirely of unique shapes. This should discourage participants from using singleton search.

Another avenue worth exploring is whether value-driven attentional capture is enhanced if participants are looking for a target within the same dimension as the rewarded distractor, or if the effects of attentional capture are persistent regardless of task. In much of the previous work, the rewarded distractors have been defined by their color – red and green items. To put it simply, would color-based reward distractors exert more control over attention when participants are engaged in a search for a color-based target, compared to when they search based on shape? The present study aims to answer this question. To do so relies on the work of dimensional weighting, which posits that humans have a limited amount of attentional "weight" that is allocated to the dimensions of stimulus (color, shape, orientation) based on their importance at the time (Muller & Krummenacher, 2006). Dimensions with more weight to them will attract more attention, leading to faster response times. Reaction times are faster when targets are within the same dimension on consecutive trials, and there are costs to switching between dimensions between trials (Muller, Heller, & Ziegler, 1995). Crucially, this work implies that previous knowledge of the dimension in the task will lead to increase weight toward that dimension.

While work on dimensional weighting hasn't explicitly been linked with reward-driven attention, it stands to reason that dimensions associated with reward would be prevalent in participants' minds, even when the stimuli are no longer being rewarded. If participants are then explicitly told to search for a target based on a dimension, and that this dimension matches the rewarded distractors, participants will see an increased effect of value-driven attentional capture due to the alignment between the dimensional search task and the distractor dimension. On trials where the cued dimension and the distractor dimension do not align, value-driven attentional capture will be reduced, as the distractor will be less salient overall.

To explore both of these theories, we conducted an experiment similar in nature to work done by Anderson, Laurent, and Yantis (2011). Participants engaged in a training phase where they were presented with colored circles and were tasked with finding the oblique line within one of the circles. The targets were consistently one of two colors, and each of these colors was associated with high and low levels of rewards. The participant received feedback after each trial. This is identical to the training phased used by Anderson et al. (2011). The test phase was composed of two different tasks – one consistent with that used in Anderson et al. (2011), labeled uncued search, and another test phase meant to test both feature search and dimensional weighting that will be labeled cued search. In the cued search task, participants were still looking at arrays for the oblique line within a shape. However, instead of being presented with shape singleton tasks, participants instead were presented with arrays composed entirely of unique shapes, each with their own color. Ahead of each trial, participants were presented with a cue indicating a key feature of their target based on one of two dimensions – shape or color. On shape cue trials, participants were told what shape to look for (triangle, diamond, etc.), and on color cue trials they were told the color (magenta, orange, etc.). As done in the previous research, the previously rewarded stimuli (red and green items) appeared in the search array to serve as distractors, though a third of trials contained no distractors. Participants were never given a cue to search for red or green; the previously rewarded colors werre exclusively shown as distractors. Based on the work done by Bacon and Egeth (1994), we expected that the cued search task will feature diminished value-driven attentional capture compared to the uncued search task, because participants were no longer be using singleton search mode. We predicted that the effects of rewarded distractors would be reduced compared to the uncued search trials. Additionally, when the cued dimension and distractor dimension aligned, i.e. color cue trials, we hypothesized that we would find greater attentional capture resulting in increased reaction times, compared to shape cue trials. Finally, we expected to see an overall effect of slower reaction times in trials with highly rewarded distractors, compared to low reward distractors and trials with no distractor present.

Methods

Participants. 25 participants, all Lehigh University students aged 18-22, were recruited for the experiment via word of mouth or flyers placed around campus. Participants reported normal color vision, and 20/20 or corrected vision with glasses/contact lenses. Participants were financially compensated for their time, at a rate of $10/hour, the duration of the experiment was roughly 50 minutes. Additionally, in one section of the experiment, participants had the opportunity to receive additional rewards based on correct trials, at a rate of $0.01-$0.05. The average level of reward earned in the training was $7. Overall, on average participants received $15 compensation for their participation in the experiment.

Apparatus. The experiment was conducted on a computer monitor in a well-lit room, with participants seated approximately three feet from the monitor. Participants input their responses to the stimuli using buttons on a gamepad.

Training phase. The first section of the experiment, referred to as the training or learning phase, was adapted from Anderson, Laurent, and Yantis (2011). Participants were first presented with a fixation point, which is meant to focus their attention on the previous screen. This was followed by an array of six uniquely colored circles (see Figure 1). Each circle contained a straight line. Five of the circles had diagonal lines, while the sixth circle possessed either a vertical or horizontal line.

Participants were tasked with locating the vertical/horizontal line and noting its orientation using the gamepad – the left trigger for a vertical line, and the right trigger for a horizontal line. The target line was always located in either a red or green circle. For each participant, one of these two colors was be defined as the high-reward target, and the other color designated as a low-reward target. The reward associations were counterbalanced by color across participants. Participants were not told these designations. When responding to a high-reward target, participants received $0.05 for a correct answer 80% of the time, and $0.01 20% of the time. On trials with the low-reward target, this distribution was reversed, as participants received $0.01 for 80% of correct answers and $0.05 the remainder of the time. Participants were given feedback on their answer, the reward gained, and their overall reward total after every trial. If the participants answered incorrectly, they were informed on the feedback screen, and if the trial timed out before a response is given they received a “Too slow!” message.

Participants had 800 ms to respond to the stimulus array once it appeared onscreen. The training phase consisted of 240 trials, broken up into six blocks of 40. Participants were also given a practice block of 20 trials before the training phase, to help them acclimate to the task. The practice block did not consist of any reward feedback.

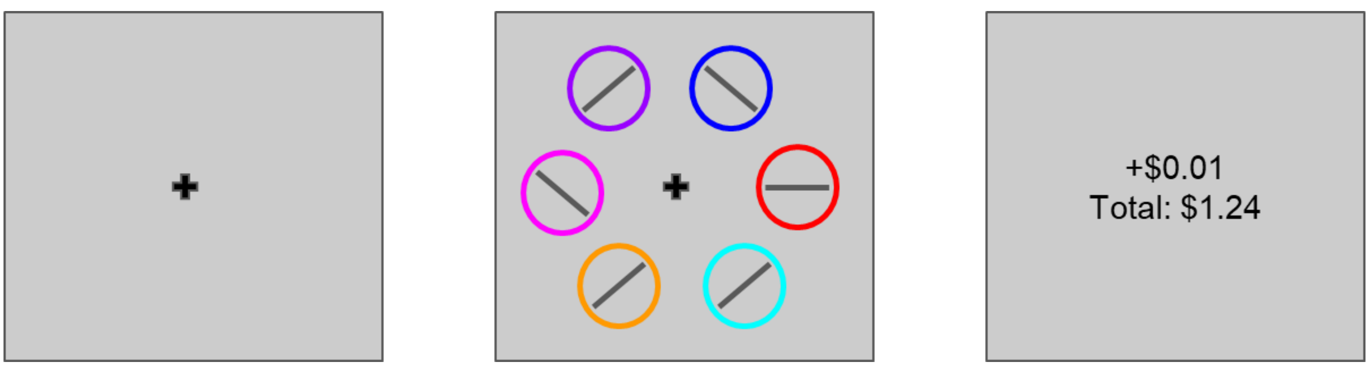

Figure 1. Example trial for training phase task. Participants will first be presented with a fixation cross to focus attention. Following this, an array of six colored circles will appear on screen, each containing a line. The target circle is the one containing a horizontal or vertical line and will always be within a red or green circle. Participants will then receive feedback on the task, including an indication of reward for correct trials.

Test phase. The test phase, or experimental phase, consisted of two different tasks: an uncued search task and a cued search task. Each task was presented separately from the other, making the experiment three separate blocks, and the order of the test phase was counterbalanced across participants to eliminate any potential order effects. Like the training phase, each test phase task consisted of 240 trials. The uncued search task was directly adapted from the training phase used in the original Anderson, Laurent, & Yantis (2011) study. In this task, participants were again tasked with finding the horizontal/vertical line within an array of shapes. The key difference from the training phase is that instead of an array consisting exclusively of circles, participants were instead tasked with finding the unique shape within the array. This is known as an oddball search task. This could mean either searching for a diamond among circles or a circle among diamonds (see Figure 2). The target was always the unique shape. On a two-thirds of all trials, one of the previously rewarded stimuli appeared in the array as a potential distractor – one-third of trials featured the highly-rewarded item, while another third featured the low-reward stimuli. The rewarded items were never the target. The final third of trials did not feature a potential distractor. Participants were given 1500 ms to respond.

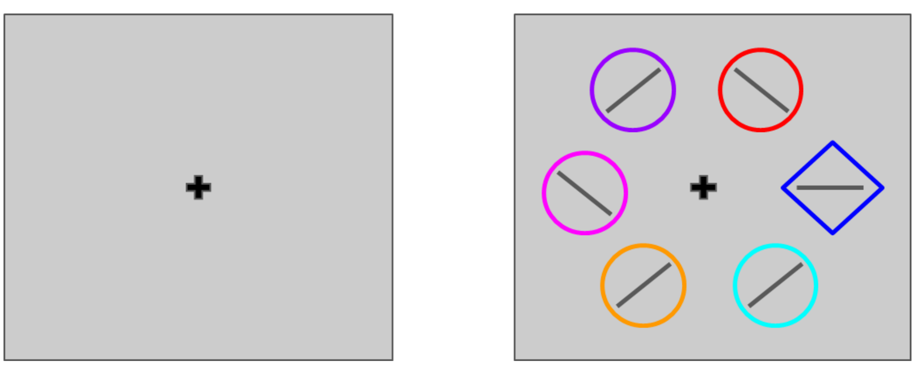

Figure 2. Example trial for uncued search task. The basic task is the same as the training phase -find the horizontal or vertical line in an array of shapes. In this phase, participants were tasked with finding the unique shape in the array. The target was always the odd shape out. On some trials, like in this image, one of the previously rewarded stimuli (red and green shapes) will appear in the array as a distractor.

Similarly, the cued search task was adapted from work done by Anderson et al. (2011), though modified to test for both the effects of feature search mode (Bacon & Egeth, 1994) and dimensional weighting (Muller & Krummenacher, 2006). In this phase, the array consisted of six unique shapes, each a different color (See Figure 2). Importantly, this made singleton search mode impossible, as the target was no longer the unique shape in the array. The general task was again the same as both the test phase and uncued search task. Ahead of each trial, participants received a cue indicating a feature of the target to be located in the array (See Figure 2a). On half (120) of the trials, the cue indicated the color of the target – i.e. blue, magenta, orange. On the remaining half of the trials, the cue indicated the shape of the target – i.e. hexagon, diamond, triangle. Similarly to the uncued search task, red and green items – the rewarded colors from the previous phase – appeared in the array as potential distractors. On a third of the trials, the high-rewarded target appeared, and on another third the low-rewarded target appeared in the array (40 trials each). The final third of the test phase contained no potential distractors. Red and green items never appeared as a target in the test phase. The stimulus appeared onscreen until response (max 2500 ms), and the cue appeared during the intertrial period.

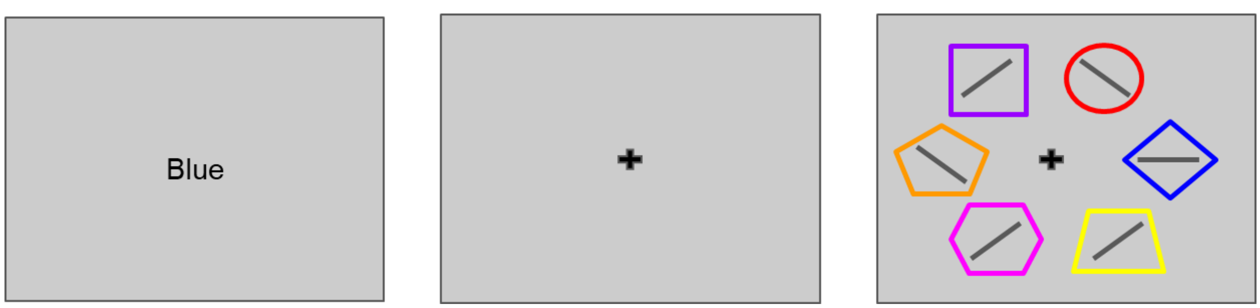

Figure 3. Example trial for cued search task. In this phase, participants were first given a cue indicating the target. This cue either provided the shape of the target or the color. Participants were then be presented with a fixation cross followed by an array of colored shapes. In this trial, one of the previously rewarded stimuli from the test phase is present as a distractor, though is only appears in a third of the trials. Another third of trials contains the second rewarded stimuli while the final third contained no distractor.

Procedure. Participants conducted the experiment on a computer. At the beginning of the experiment, participants were provided with their informed consent documents and given brief oral instructions explaining the experiment in general and the learning phase more specifically. Participants completed a short practice block and then the learning phase. After the learning phase, participants then were given new instructions focusing on the test phase. Similarly, they then completed a short set of practice trials and then the actual experimental phase. At the end of the experiment, participants were briefed on the purpose of the experience and received their financial compensation. The experiment took roughly 50 minutes in total.

Analysis. Analysis was conducted using a 3 x 3 within-subjects ANOVA on SPSS Statistics. We looked at the effects of two different independent variables – Cue Condition and Distractor Presence. Cue Condition has three factors: Uncued, Color Cue, and Shape Cue. Distractor Presence has three factors: High-Reward, Low-Reward, and No Distractor. We measured how these variables influence participants' reaction time and accuracy. In addition to looking across tasks, we also wanted to analyze the effects of reward within each individual task, using a one-way ANOVA. Lastly, we also analyzed participants' reaction times and accuracy results for the training phase of the experiment, to determine if there were any significant effects of reward within the original task.

Results

We predicted that there would be an effect of search mode such that the effects of reward would be diminished in cued search tasks compared to uncued search. Additionally, we predicted that color cues would heighten salience of color overall and specifically the color-based rewarded distractors, such that color cues would show increased effects of value-driven attentional capture as compared to shape cue trials.

In addition to analyzing the effects of the test phase tasks, we also analyzed the training phase trials to see whether participants performed differently on trials featuring the high-rewarded target compared to the low-reward target. Using a dependent means t-test, we found a significant effect of reward ($t(23) = 3.145$, $p = .005$), such that participants responded significantly quicker to the high-reward target ($M = 523$ ms) in comparison to the low-reward target ($M = 535$ ms). This indicates that rewards aided search efficiency when directly relevant to the search task. Interestingly, when asked, some participants did not express awareness of any pattern of reward distribution, or any relationship between the targets and reward levels. However, these responses were not systematically evaluated across all participants and are purely anecdotal. Still, it could indicate a subconscious manipulation of attention.

Next, a one-way ANOVA was performed on the results of the uncued search task, which was directly adapted from the test phase in Anderson, Laurent & Yantis (2011). We aimed to compare the effects of distractor presence on participant reaction times. We found an overall effect of reward ($F(2, 46) = 4.744$, $p = .013$). In particular, we found a significant difference between trials featuring the highly rewarded distractor ($M = 668$ ms) and trials with no distractor present in the array ($M = 651$ ms). Low-reward distractor trials ($M = 657$ ms) were also slightly slower than trials featuring no distractor, though this finding was not significant. The pattern of results can be seen in Figure 4. Overall, these findings indicate that we were able to generate effects of value-driven attentional capture such that the presence of rewarded distractors caused participants to respond more slowly.

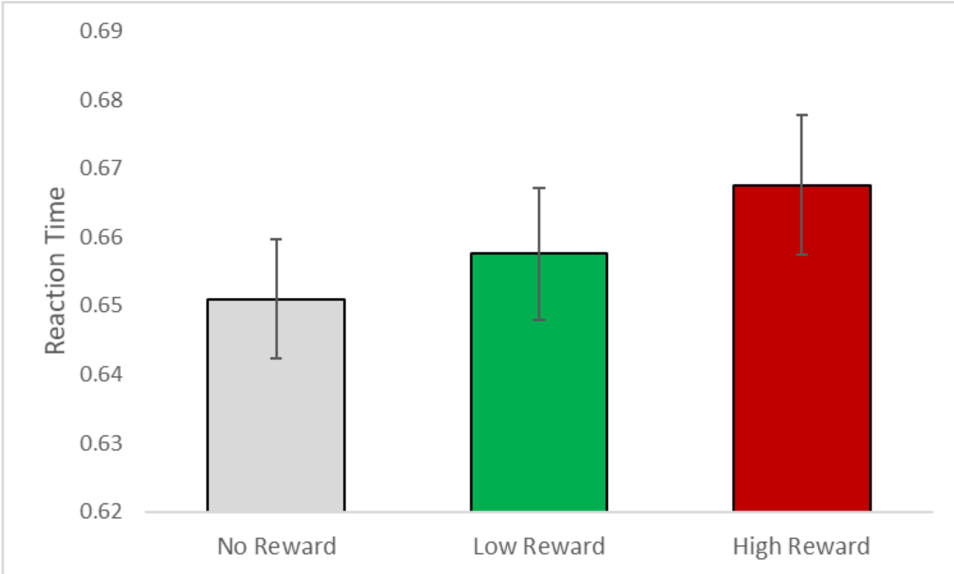

Figure 4. Reaction time results for uncued search. Participants responded significantly slower when the high reward distractor was present compared to when the low reward distractor was present and no distractor was present at all. This indicates effects of value-driven attentional capture, such that participants formed reward-stimuli associations and that these associations were also dependent on the level of reward. Error bars indicate standard error.

Next, a 3 x 3 within-subjects ANOVA was used to compare the uncued search task to both cued search conditions (color cue and shape cue) and to see if the effect of reward, if any, varied across conditions. Figure 5 plots all conditions. Results indicated only a significant effect of task ($F(2, 46) = 60.886$, $p < .001$). Shape cue search trials ($M = .895$) were significantly slower than both color cue trials ($M = .721$) and uncued search trials ($M = .659$). There was no overall effect of reward ($F(2, 46) = .107$, $p = .899$) when analyzing all conditions. Despite a significant effect of reward on uncued search trials, value-driven attentional capture effects seemingly vanished in both cued search trials. Additionally, there was no significant interaction effect between Cue Condition and Reward Level ($F(4, 92) = 1.351$, $p = .257$). This seems to discount any possible effects of dimensional weighting, as we initially predicted a significant effect between color cue and the presence of rewarded distractors.

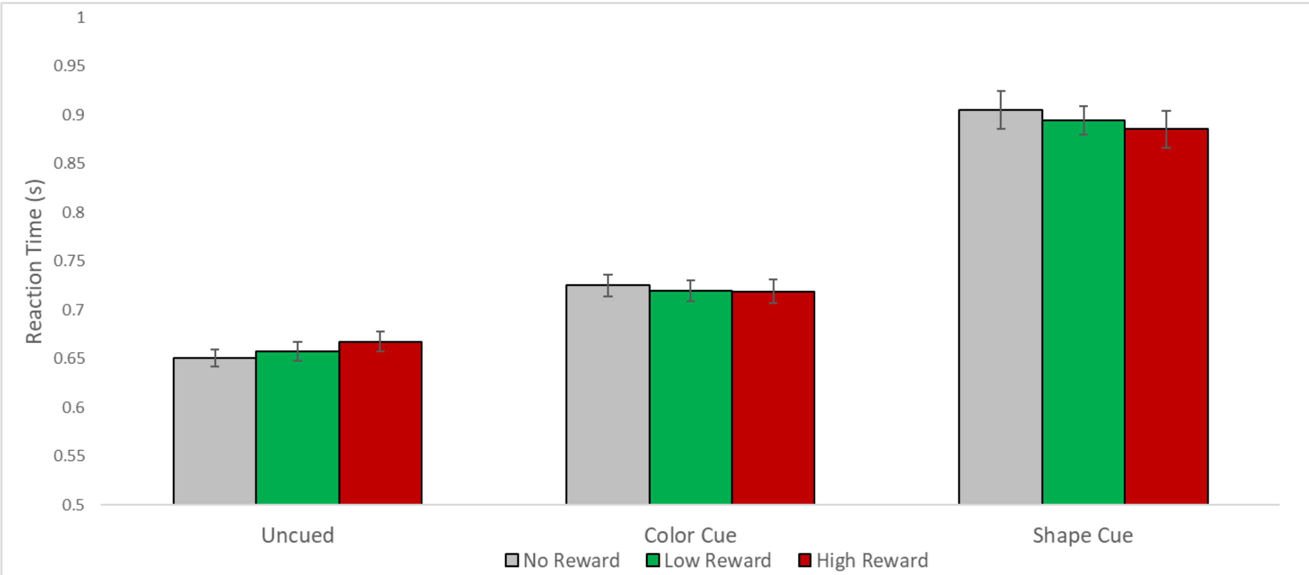

Figure 5. Reaction time results across all conditions. There was no significant effect of reward across when comparing across all conditions. Value-driven attentional capture effects were not apparent in either the color cue or shape cue conditions. Additionally, there was no interaction between cue and reward, though we expected to find increased attentional capture in the color cue condition compared to the shape cue condition. Error bars represent standard error.

When looking at accuracy results, we did not find any effects of value-driven attentional capture. Even in the uncued search task, which showed significant results for reaction time, had no significant effect of reward ($F(2, 46) = 1.885$, $p = .163$). When comparing across all cue conditions, we only found a significant effect of task ($F(2, 46) = 10.557$, $p < .001$), similarly to reaction time results. There was no effect of reward level ($F(2, 46) = .822$, $p = .446$) or an interaction between reward level and cue condition ($F(4, 92) = .215$, $p = .929$). All accuracy results can be seen in Table 1. One possible explanation is that each task was easy enough that the presence of rewarded distractors could not demonstrably effect participants responses, and only their reaction times.

Table 1

Accuracy Results By Percentage Correct Across Conditions

Cue Condition	No Reward	Low Reward	High Reward
Uncued	92.4	93.8	93.4
Color	90.4	90.5	91.1
Shape	87.9	88.1	88.5

Discussion

The purpose of this study was to explore the effect that reward has on attention. Specifically, we wanted to investigate how reward associations can linger and attract our focus even when no longer relevant or related to the task hand, a concept known as value-driven attentional capture. Past research has found that previously rewarded stimuli can capture attention even when not physically salient or related to the current goals of the task (Anderson, Laurent, & Yantis 2011), upending the traditional endogenous/exogenous dichotomy of attention. Our study aimed to push the limits of value-driven attentional capture, and how this effect can change given different contexts. Specifically, wanted to determine whether value-driven attentional capture was present when participants engaged in non-singleton search tasks. Additionally, we wanted to see whether making the overall dimension of reward-stimuli associations more salient would lead to increased attentional capture of the rewarded distractors. To do this, we attempted to recreate the effects of value-driven attentional capture using the same experimental paradigm as Anderson, Laurent & Yantis (2011). Additionally, we wanted to capture participant performance on these established tasks to a search task composed of unique shapes and colors, which would force participants away from singleton search mode. We also provided participants with cues indicating either the color or shape of the intended target to see if that would activate increased dimensional salience. We predicted that based on the work done by Bacon & Egeth (1994) on overriding attentional capture that resorting to feature search in the uncued search task would lead to diminished effects of value-driven attentional capture compared to the cued search tasks. Additionally, we expected that, according to dimensional weighting work (Muller & Krummenacher 2006), color cues would lead to increased dimensional salience of colors in general and thus make the color-based distractors more salient, leading to increased attentional capture as compared to shape cue trials.

The results of our study indicated that we were able to successfully generate value-driven attentional capture. The training phase of our experiment successfully led to associations between stimuli (colored circles) and varying levels of reward. This was demonstrated via slower response times in an uncued search task when rewarded distractors were present. In particular, trials featuring the highly-rewarded distractor had significantly slower response times compared to trials where no distractor was present. This demonstrates that our training phase worked as intended.

In our cued search phase results, we found that value-driven attentional capture effects disappeared completely, to the point that there was no significant effect of reward within color cue or shape cue tasks. This lends credence to the idea that Bacon & Egeth's (1994) work on search mode can be applied to reward-based salience in addition to physical salience. When searching through more complex arrays that require the use of feature search mode, value-driven attentional capture may be overridden. We predicted that this would lead to a diminished effect as compared to the uncued search task, though we did not anticipate it vanishing completely. However, there is another crucial factor to consider when interpreting these results – the presence of cues. Participants were provided with information on the target ahead of every single trial, which allowed them to focus their attention. While Bacon and Egeth (1994) did not look at cues in their study, it is possible that they also encouraged participants to engage in feature search mode over singleton search mode. Since they were given cues base on the feature of the target, it could steer them away from focusing on singleton search, in conjunction with the array of unique shapes. Future work should look to isolate these effects in turn. Cues should be applied to singleton search tasks, and more complex arrays requiring feature search mode should be tested independently from cued search tasks to determine if each can override value-driven attentional capture individually.

While these results would seem to at least somewhat support feature search mode's ability to override attentional capture, it contradicts some other findings in this field. Work done by Feldmann-Wustfeld, Brandhofer, and Schubo (2016) found that rewarded distractors only seem to capture attention in heterogeneous contexts. In this study, participants were presented with arrays containing either identically oriented lines, with one unique target based on orientation and one unique distractor based on color, or an array where the lines could be both horizontal and vertical. ERP results found that high-reward distractors only captured attention, indicated via a higher N2pc component, in the heterogeneous tasks. This would seemingly go against the present findings, which found that value-driven attentional capture disappeared when participants were searching through a heterogeneous array. This could bolster the idea that cued search overcame value-driven attentional capture rather than feature search, though more work should be done to replicate these findings and compare them against each other.

The final results of our study attempted to determine if the impact of dimensional weighting had any impact on value-driven attentional capture. Since the rewarded stimuli of

Anderson, Laurent & Yantis (2011) are based on colors, we hypothesized that making color a more salient dimension overall would also activate increased salience of the rewarded stimuli when present as distractors, leading to increased attentional capture. We tested this by giving participants cues prior to the search array, either indicating the color or shape of the target. While we expected color cue trials to have increased value-driven attentional capture, our results did not indicate this. In both cue trials, there was no significant effect of reward. The only significant difference was that shape cue trials were significantly slower than both color cue and uncued search. This could be because participants struggled overall with searching for shapes, or that shapes are processed later in visual pathways. Again, it may be hard to determine if this means dimensional weighting has any meaningful impact on value-driven attentional capture, because it could have been overridden completely by both cues and feature search mode. Future research should attempt to explore this concept on its own to make a clearer determination.

One of the most intriguing aspects of value-driven attentional capture is that it serves as a separate concept of attention from both goal-driven and stimulus-driven attentional capture. However, this additional domain of attention may not be exclusively tied to rewards. Another possible theory is that some aspect of attention is related to emotions and reactions. The basis for this theory stems from research showing threat-associated stimuli can serve as distractors in a similar way to those associated with reward (Schmidt, Beloposky, and Theeuwes, 2015). In the training phase of this experiment, one of the target stimuli was consistently associated with a small electrical shock, generating a fear-based association. In the test phase, this fear-associated stimulus captured attention, even when it was no longer associated with the shocks. This indicates that this third dimension of attention may be based on learned history or emotional association, as opposed to exclusively being reward-driven. Value-driven attentional capture may simply be a subset of positive emotional attention. Further research is needed to explore this theory.

As the study of value-driven attentional capture is still relatively young, there are multiple avenues of research as yet unexplored. Do participants have to be explicitly rewarded with money, or can the same effects be engendered with something like candy or even arbitrary point totals? Can it be found in more complex tasks, and ones that are more applicable to real-life situations? All these questions and more are worth exploring, but that does not discount the value of the present research. Value-driven attention expands the original conception of how attentional systems operates and provides key insights into exploring human behavior. This work could have serious implications for present-day society, where more and more things are becoming gamified and associated with rewards. With the ubiquity of social media and the increasing need for likes, views, and subscriptions, humans may become primed to respond to reward-driven attentional cues. Are we more distracted now because of these increased reward-stimuli attentions? This could also be potentially useful in the field of addiction, where understanding of how rewards distract from current behavior could have implications on future treatment. While the work done on value-driven attentional capture has so far been focused on simplistic tasks and stimuli, it is foundational for exploring more realistic contexts and scenarios. The purpose of our research was to see if value-driven attentional capture can persist even when participants have to look through more complex arrays. The results indicate that it diminishes or vanishes altogether, which could indicate that value-driven attentional capture does not have much real-world application. However, this only serves as the beginning of a thorough investigation into these processes. Future work could look at the level of reward, the complexity of the stimuli, and applications in real world situations. Reward is a fundamental part of our society, and investigating how it influences our attention is crucial in obtaining a complete picture of human behavior within reward-based contexts.

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