Theses and Dissertations

December 2014

Reward Distracters and Working Memory Performance

Tara Ann Miskovich
University of Wisconsin-Milwaukee

Follow this and additional works at: https://dc.uwm.edu/etd

Part of the Psychology Commons

REWARD DISTRACTERS AND WORKING MEMORY PERFORMANCE

by

Tara A. Miskovich

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Psychology

at

University of Wisconsin-Milwaukee

December 2014

ABSTRACT
REWARD DISTRACTERS AND WORKING MEMORY PERFORMANCE

by

Tara A. Miskovich

The University of Wisconsin-Milwaukee, 2014
Under the Supervision of Associate Professor Christine L. Larson, Ph.D.

Past literature has demonstrated that reward stimuli capture attention involuntarily, much like salient stimuli or other emotional stimuli (e.g., threat). In addition, even previously rewarded stimuli capture attention when they are not task-relevant. Recent evidence has demonstrated that affective stimuli have preferential access to working memory stores, even when they are task-irrelevant distracters. The current study aimed to assess the potential impact of attentional capture of task-irrelevant reward stimuli on filtering efficiency into working memory. It was predicted that this attentional capture of stimuli representing reward may impact ongoing goal-directed behavior by impairing the encoding of task-relevant information into working memory and potentially enhancing distracter processing. The results did not support this hypothesis that there would be a differential impairment with the presence of a reward distracter.

iii

To my parents, Pete and Carol, who have been my greatest inspiration. Also, to my wonderful fiancée, Schuyler, whose love and support has helped me through this process.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

We are bombarded with a tremendous amount of rich environmental stimuli at any given moment. To cope with this, we have evolved shortcuts to facilitate adaptive allocation of cognitive resources. Specifically, two mechanisms of attention selection help us determine how we should allocate our limited attentional resources (Anderson, 2013; Corbetta & Shulman, 2002). Top-down processes help us focus attention on goal-related stimuli, while bottom-up processes help us assess salience of incoming stimuli and draw attention toward such stimuli if warranted (Corbetta & Shulman, 2002; Theeuwes, 2010). These two mechanisms work together in order to encourage broader goal-directed behavior while keeping the organism attuned to salient information in the environment that may warrant shifting of attentional resources (Anderson, 2013; Corbetta & Schulman, 2002).

It is well documented that stimuli that are physically salient (e.g. the color red) (Fortier-Gautherier, Dell'Acqui, & Jolicoeur, 2013), engage the bottom-up mechanism and capture attention involuntary (Theeuwes, 1992). In addition to physical salience, evidence has indicated that we divert attentional resources to certain emotional stimuli (Vuilleumier & Huang, 2009), such as threat (Bannerman, Milders, & Sahraie, 2010; Bishop, 2008), regardless of its relevance to current task goals (Bishop, 2007). However, much less is known about the impact of rewarding stimuli on these processes. Prior evidence has demonstrated an attentional bias for certain pleasant stimuli such as positive faces that may be rewarding (Hodsoll, Vinding, & Lavie, 2011), but it is hard to determine if a learned association drives the associated attentional-bias or if these stimuli are inherently salient (Anderson Laurent, & Yantis, 2011, Anderson, 2013). To tease apart the effect of learned associations, recent literature has focused on experimentally

manipulating stimuli-reward associations to assess the impact on attentional selection. For instance, some studies have demonstrated that efficiency in visual search increases when target items are associated with reward (Kiss, Driver, & Eimer, 2009; Kristjánsson, Sigurjónsdóttir, & Driver, 2010), indicating a potential attentional bias toward reward stimuli. In addition, Della Libera and Chelazzi (2006) and Hickey, Chelazzi, and Theeuwes (2010) demonstrated that when certain stimulus features are associated with the receipt of a high reward over a low reward on one trial, these features are more quickly recognized in a target in the next trial. Alternatively, when stimulus features for a target that received a high reward on the prior trial now represents a distracter, responses are slower than if their prior response received a low reward. This effect has been termed "reward priming" and refers to how receipt of a reward effects the allocation of attention on the following trial (Della Libera & Chelazzi, 2006; Hickey, et al., 2010).

The evidence demonstrating that reward increases visual search efficiency and modulates priming of attention for future trials has led some to argue that stimuli that are not inherently salient or affective, but have been previously rewarded, are also preferentially attended to (Anderson et al., 2011; Anderson, 2013; Della Libera, Perlato, & Chelazzi, 2009). It has been argued that reward may influence attention in a way that cannot be explained entirely by the previously discussed two mechanisms of attentional selection (Anderson, 2013; Awh, Belopolsky, & Theeuwes, 2012). Anderson (2013) proposed the addition of another mechanism of selective attention identified as the value-driven mechanism of attention, in which previously rewarded stimuli are readily identified in the environment. Much like with bottom-up attentional selection, current goal-related attention may be disrupted in favor of attending to stimuli that are not

inherently salient, but have been associated with reward in the past (Anderson et al., 2011; Anderson, 2013; Theeuwes & Belopolsky, 2012).

Although evidence from visual search and reward priming paradigms lend evidence to the existence of a value-driven mechanism of attention, driven by the properties of the stimuli, one could argue that these effects merely demonstrates how reward modulates the deployment of the top down goal-directed mechanism (Anderson, 2013). Indeed many studies have demonstrated that reward can be a powerful motivator to increase performance in goal-related tasks (Pessoa & Engelmann, 2010). However, several recent studies have shown that previously rewarded stimuli seem to capture attention, even when they are no longer relevant to current goals (e.g. Anderson et al., 2011; Anderson & Yantis, 2012; Theeuwes & Belopolsky, 2012). For instance, in a Stroop task participants improved performance when a color was rewarded with correct identification (naming the ink) but performance was impaired when they had to inhibit reading the name of the rewarded color (Krebs, Boehler, & Woldorff, 2010), indicating that irrelevant reward information can impair task-relevant performance. Anderson and colleagues (2011) conducted a series of experiments that provided further evidence of the distracting effect of previously rewarded stimuli. They found that previously rewarded information captures attention when it is no longer relevant to current task goals. When a previously rewarded stimulus was used as a distracter in a non-rewarded attention task, reaction times were slowed, indicating a processing cost of having a reward distracter present (Anderson et al., 2011).

One could argue that this cost is not necessarily due to attentional capture of the distracter, but could reflect other processes such as arousal (Anderson, 2013; Qi, Zeng,

Ding, & Li, 2013; Theeuwes & Belopolsky, 2012). Recent evidence has dispelled this notion with evidence from eye-tracking that demonstrated initial ocular movements towards highly valued stimuli prior to relevant target items (Anderson & Yantis, 2012; Theeuwes & Belopolsky, 2012). In addition, Qi et al. (2013) recorded event-related potentials during an adaptation of the Anderson et al. (2011) task and demonstrated that previously rewarded stimuli captured attention by eliciting an N2pc, an ERP component that reflects early attention, prior to the target. Anderson (2013) argues that collectively this evidence demonstrates the existence of another adaptive system, arguably similar to the bottom-up mechanism that works by disrupting current goal-driven behavior to attend to important stimuli in the environment. Unlike the bottom-up mechanism of attention, the value-driven mechanism requires a learned component from the organism to recognize these rewarding opportunities in the environment.

Although the attentional bias toward previously rewarded information has been well established in the literature, little is known about the downstream behavioral consequences of this bias. Working memory, which has been called the "blackboard of the mind" (Goldman-Rakic, 1996, p. 13473), allows us to hold and manipulate information in an effort to direct goal-related behavior (Baddeley, 2012; Cowan, 2005). Attentional control is thought to act as the "gatekeeper" of information that goes on to be maintained in working memory (Awh, Vogel & Oh, 2006). Given our limited capacity to hold information in working memory (Luck, & Vogel, 1997), we must rely on these aforementioned mechanisms of selective attention in order to capture the most important information in the environment and filter out irrelevant information from entering working memory stores (Fukuda & Vogel, 2009; Vogel, McCollough, &

Machizawa, 2005). These processes are especially important when we are engaging in cognitive control, which requires working memory resources in order to maintain attention on goal-related tasks (Miller, 2000).

Although evidence has shown that affective stimuli (both threat and reward) capture attention (e.g. Anderson et al., 2011; Bishop 2008), little is known about how emotionally salient yet distracting information may also impact filtering information into (or out of) working memory, which may impact ongoing behaviors (Stout, Shackman, & Larson, 2013). Prior neuroimaging research has demonstrated the distracting effect of emotional stimuli during working memory maintenance, showing that neural regions associated with holding task relevant information in working memory are less active when presented with an emotional distracter, while regions important for emotional processing demonstrate increased activity (Dolcos & McCarthy, 2006). This indicates that cognitive control regions involved in active maintenance of relevant information go offline in favor of processing non-relevant emotional stimuli. Stout et al. (2013) then demonstrated that irrelevant fearful information has privileged access to working memory stores over relevant neutral information by looking at the impact of distracters in the encoding phase of a working memory task. They demonstrated through an ERP component that is thought to reflect working memory storage (the contralateral delay activity) that fearful face distracters are more likely to be encoded and stored in working memory over neutral face distracters, indicating that fear is hard to ignore. No study to our knowledge, however, has examined the impact of distracting reward stimuli on filtering efficiency into working memory.

Current Study

The purpose of the current study is to examine the impact of rewarded distracters on filtering efficiency into working memory by measuring behavioral indicators of working memory capacity for target items and filtering efficiency. As stated, research has demonstrated the attentional bias of previously rewarded stimuli, as evident by longer processing time and attentional capture (Anderson et al., 2011; Anderson & Yantis, 2012; Theeuwes & Belopolsky, 2012), but no one has examined the extent to which irrelevant reward distracters impair encoding and maintaining goal-relevant information. Much like neurocognitive models of anxiety and threat (Bishop, 2007) there may be behavioral consequences of reward distraction such as unnecessary storage of irrelevant rewarding distracters in further downstream processing. For instance, excess distraction could lead to storage in long-term memory that could result in intrusive thoughts and further disruption of goal-related behavior. It was predicted that efficient filtering of goal-relevant items into working memory would be impaired when a distracter that was previously associated with a reward is present, due attentional capture of the reward stimuli. To examine this, we measured K, a behavioral measure for working memory capacity for targets that accounts for hits and false alarms, as well a filtering cost, which is a behavioral measure of inefficiency in filtering out distracters from entering working memory (Fukuda & Vogel, 2009). It was predicted that K scores would be lower when a reward distracter is present in an array of distracters and targets than when all distracters are emotionally neutral, demonstrating impaired target encoding. In addition, filtering cost scores, indicating poorer filtering efficiency of distracters, were predicted to be higher when a reward distracter is present. This might indicate that this value-driven

mechanism of attentional selection (Anderson, 2013) results in privileged access to working memory.

In more exploratory analyses we examined how individual differences in sensitivity to reward, impulsivity, and working memory capacity may modulate the effects of the distracting effect of irrelevant reward on working memory. We predicted that higher reward sensitivity and impulsivity would be related to greater impaired target processing and poorer filtering into working memory when a reward distracter is present.

This study builds on prior research to help us better understand the extent to which previously-rewarded distracters not only capture attention but may disrupt ongoing goal driven behavior by impacting what information is encoded into working memory. Understanding the downstream consequences of value-driven attention may yield a neurocognitive model to better understand the etiology of a number of forms of psychopathology characteristic of reward dysfunction (e.g. addiction, obesity) (Anderson et al., 2011). By delineating a mechanism via which attention is drawn involuntarily to learned reward, we may be able to better understand how this mechanism can maladaptively disrupt ongoing goal-directed behavior in these disorders.

Method

Participants

Sixty-nine participants (39 female) were recruited from the University of Wisconsin-Milwaukee student population in exchange for extra-credit for courses (M = 22.96, SD = 6.04). Participants had to be at least 18 years old, proficient in English, and have no visual impairment. Subjects were provided written informed consent prior to participation and the study was approved by the University of Wisconsin, Milwaukee's

Institutional Review Board. Two participants' data were dropped due to non-compliance with experimental procedures. One participant was excluded due to the possibility of color blindness. One participant was missing data from the test phase. Nine participants were excluded due to performance (see data cleaning below).

Primary Task

Participants completed a behavioral study in which working memory capacity and filtering efficiency was assessed using both emotionally neutral- and reward-related distracters. We used an adaptation of the attention task used by Anderson and colleagues (2011). We modified this task to resemble prior working memory and filtering tasks (Fukuda & Vogel, 2009; Vogel et al., 2005) in order to assess how previously rewarding but irrelevant stimuli impact working memory performance. Participants completed two working memory change detection tasks that involve a visual search, training phase followed by a test phase. First participants were run on the training phase, which consisted of 240 trials, in which participants were instructed that they had the opportunity to win money based on their performance, but were not told the specific contingencies. Participants were instructed to pay attention to an array of six different colored circles (each 2.3° x 2.3° visual angle) with bars of varying orientation inside of each. Each circle was placed equally around the fixation point along an imaginary circle (3.3° radius with a 0.5° x 0.5° fixation cross at the center). Each trial began with a 2000ms screen with "get ready" centered on the screen. For each trial, they were instructed to pay attention to the orientation of a bar inside either the red or the green target (only one target per trial) displayed in the brief array of the six circles (300ms), and to remember them over a short delay (900ms). After the delay the array was displayed again (the probe) and they were

instructed to identify either a change (of 45 degrees) or no change of the bar orientation inside target items. On 80% of the trials, correct identification of only one of the colored targets (red or green) yielded a 10-cent reward, which participants were notified via a feedback screen indicating a correct response and the reward won. Correct responses for the other colored target did not yield a reward. The purpose of training these contingencies was to imbue one colored circle with affective salience (reward), while the other colored circle will remain affectively neutral.

Next, in the test phase, participants were told they would perform another task in which they would not receive any monetary rewards. In this phase, participants completed a similar working memory task (same timings) as the training phase, but were now instructed to pay attention to the item shape and to remember the orientation of bars inside any diamonds and to ignore all circles (shapes are counterbalanced). After the delay, they were asked to make a judgment if any of the bars enclosed in target items (diamonds) had changed in orientation. Targets from the training phase were included as items that participants have to ignore. The important conditions in the test phase were: 1.) two affectively neutral targets (diamonds in colors other than red or green) alone (NT2), 2.) two neutral targets with four neutral distracters, including the previously non-rewarded target in the training phase (ND), 3.) two neutral targets with three neutral distracters and one distracter that was the previously rewarded target from the training phase (RD) and 4.) two neutral targets with four neutral distracters that did not include either of the target colors from the training phase (NDnew). By including a distracter that was previously associated with a reward (RD), we were able to assess the impact of goal-irrelevant reward distraction on working memory storage of target or goal-relevant

information into working memory. Each condition had 34 trials and the order was
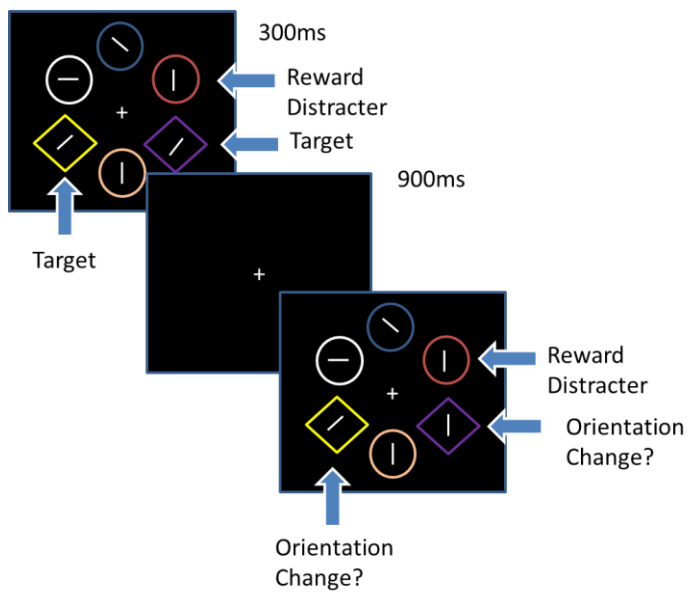
randomized.

a.)

b.)

Figure1. a.) Example of the training phase, in which participants learn that one of the two colored targets, is associated with a reward with correct identification, whereas the other target does not yield a reward or feedback with correct identification. **b.)** Example of the test phase, in which participants are instructed to ignore circles and pay attention to the orientation of the bars inside of the diamonds. The two targets from the training phase, both rewarded and non-rewarded, now serve as distracters to be ignored.

Self-report Measures

We collected measures of sensitivity to reward by administering the Sensitivity to Reward and Punishment scale (Torrubia, Avila, Moltó, & Caseras, 2001), which has two scales for sensitivity for reward and punishment. Both the SR and SP scales have demonstrated good internal consistency and reliability at 3 months (alpha = .83 and .78, r= .89 and .87, respectively). We also collected the self-report Behavioral Activation Scale developed by Carver and White (1994) to assess individual differences in the behavioral activation and behavioral inhibition systems. This measure has demonstrated good psychometric properties related to test-retest reliability, internal consistency, and convergent and discriminant validity (Carver & White, 1994). In addition, we assessed impulsivity with the Barratt Impulsiveness Scale (BIS-11) (Patton, Stanford, & Barratt, 1995). This measure has demonstrated internal consistency with alpha ranging from .79-.83 in various populations (Patton et al., 1995).

Working Memory Capacity

To understand how individual differences in working memory capacity may influence one's ability to filter out reward distracters we measured basic visual working memory capacity using a basic change detection task modeled after Luck and Vogel (1997). The task consisted of three different conditions, 2 targets, 4 targets, or 6 targets over 120 trials. The task required participants to remember an array of colored squares

shown very briefly (100ms). After a brief delay (900ms) participants were shown only one of the squares from the previous array and were asked to determine if the probe square has changed in color (Luck &Vogel, 1997).

Data Cleaning

Data analysis focused on data collected in the test phase. Subjects performing at or below 50% in any of the key conditions were dropped from further analyses (n = 7). All trials where response to the probe exceeded 5000 ms were also dropped. From here any trials that were greater than or less than three standard deviations away from the mean reaction time were considered outlier responses and removed from further data analyses (Anderson et al., 2011). The average amount of trials dropped total per subject was 4.9 (3.6%): NT2 (M = .88), RD (M = 1.09), ND (M=1.51), NDnew (M = 1.52). There was a significant difference in amount of trials dropped per conditions [F(3, 198) = 6.954, p <.001]. Post hoc tests revealed that there were significantly more NDnew and ND trials dropped compared to NT (p = .001 and p =.005 respectively). Subjects were excluded if 20% or more of all trials were dropped (n = 2).

Task Dependent Variables

To assess the extent to which individuals had trouble preventing task-irrelevant rewarding stimuli from entering working memory, we used two primary dependent variables, Pashler's K and filtering cost scores. Pashler's K formula $K = S \times (H - FA)/(1-FA)$ is a behavioral measure of working memory capacity for targets that considers both hits and false alarms (Pashler, 1988). We calculated this for the four key conditions in the test phase: 1) two targets and four distracters, one of which was the previously associated reward stimuli (RD); 2) two targets and four distracters, one of which is the previously

learned neutral target (ND); 3) two targets and four distracters that do not include the colors of the two targets from the training phase (NDnew); and two targets and no distracters (NT2). The inclusion of the two target condition allows us to compare the effect of having distracters present.

In addition, I will examine filtering cost scores across conditions. The filtering cost score is an indicator of the efficiency of filtering distracters from entering working memory and takes the difference in average target accuracy between trials with only two neutral targets (NT2) and trials with additional distracters (Fukuda & Vogel, 2009). Therefore, a filtering cost score of "0" would indicate perfect filtering, while anything above that indicates impaired filtering of distracters from working memory. We calculated the filtering cost score for the three distracter conditions: RD, ND, and NDnew.

It is important to note that we did not include an analyses of reaction time in this study. The decision not to include an analysis of RT was due to the fact that accuracy during the working memory task was emphasized while speed was not.

Results

Effect of Distracters on Working Memory Capacity

To test the impact of a rewarding distracter on working memory capacity for target items a repeated measures ANOVA was conducted to compare working memory for targets (Cowan's K) in each of the four conditions (NT, RD, ND, NDnew). There was a significant effect of Condition [$F(3,165) = 45.037$, $p < .001$]. Bonferroni corrected pairwise comparison demonstrated that NT was significantly different from the other three conditions ($p < .001$). There were no significant differences in K scores between the

three distracter conditions (p = 1). This indicates that working memory for targets is greater when there are no distracters present, but when distracters are present there was no difference across conditions.
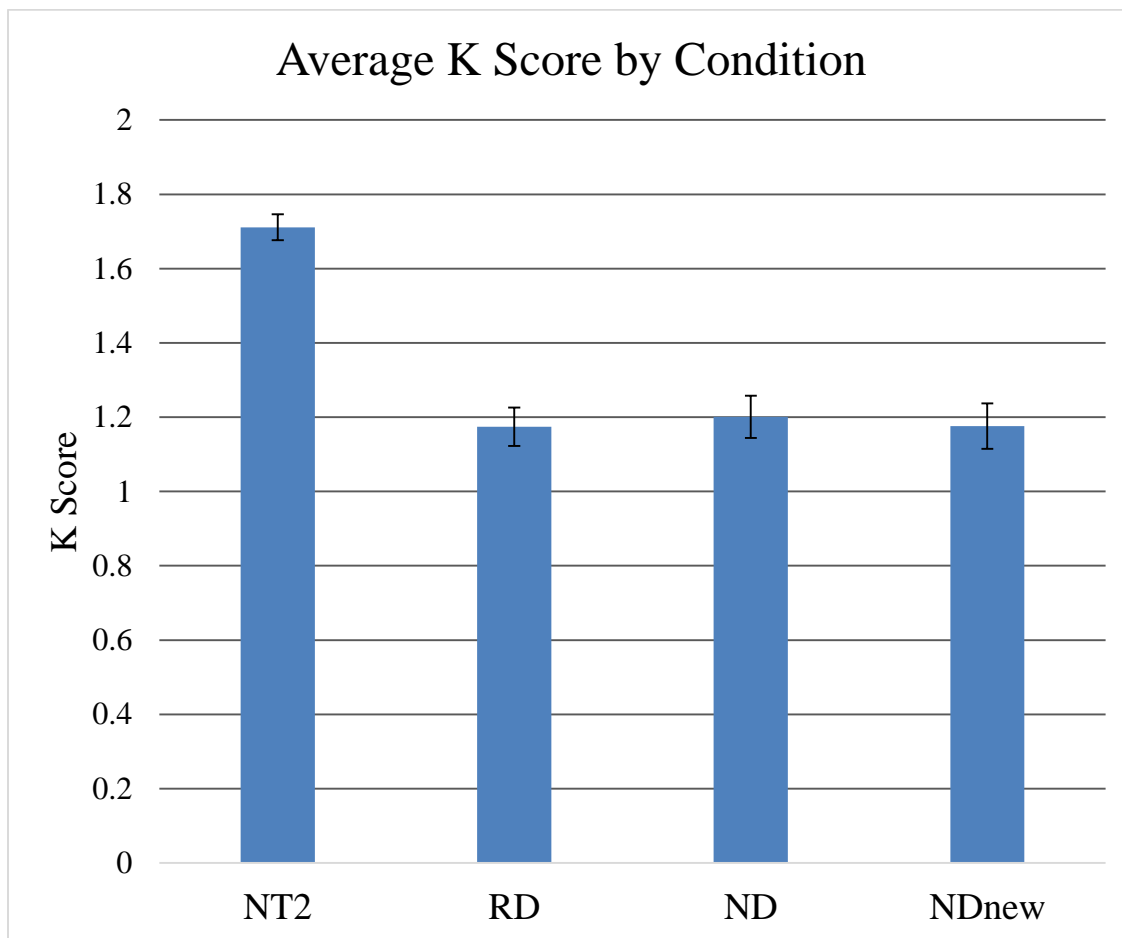
Figure2. Average working memory capacity for targets (K) by condition. K was significantly higher in the condition with two neutral targets alone compared to conditions with distracters present (p<.001).

Effect of Distracters on Filtering Efficiency

To test the impact of a reward distracter on filtering efficiency a repeated measures ANOVA was conducted to compare filtering cost scores for the three distracter conditions (RD, ND, NDnew). There was no significant effect of condition [F(2, 110) = .145, p = .865]. This indicates that filtering efficiency is similar across all distracter conditions, and there was no effect of distracter valence.

Average Filtering Cost by Condition

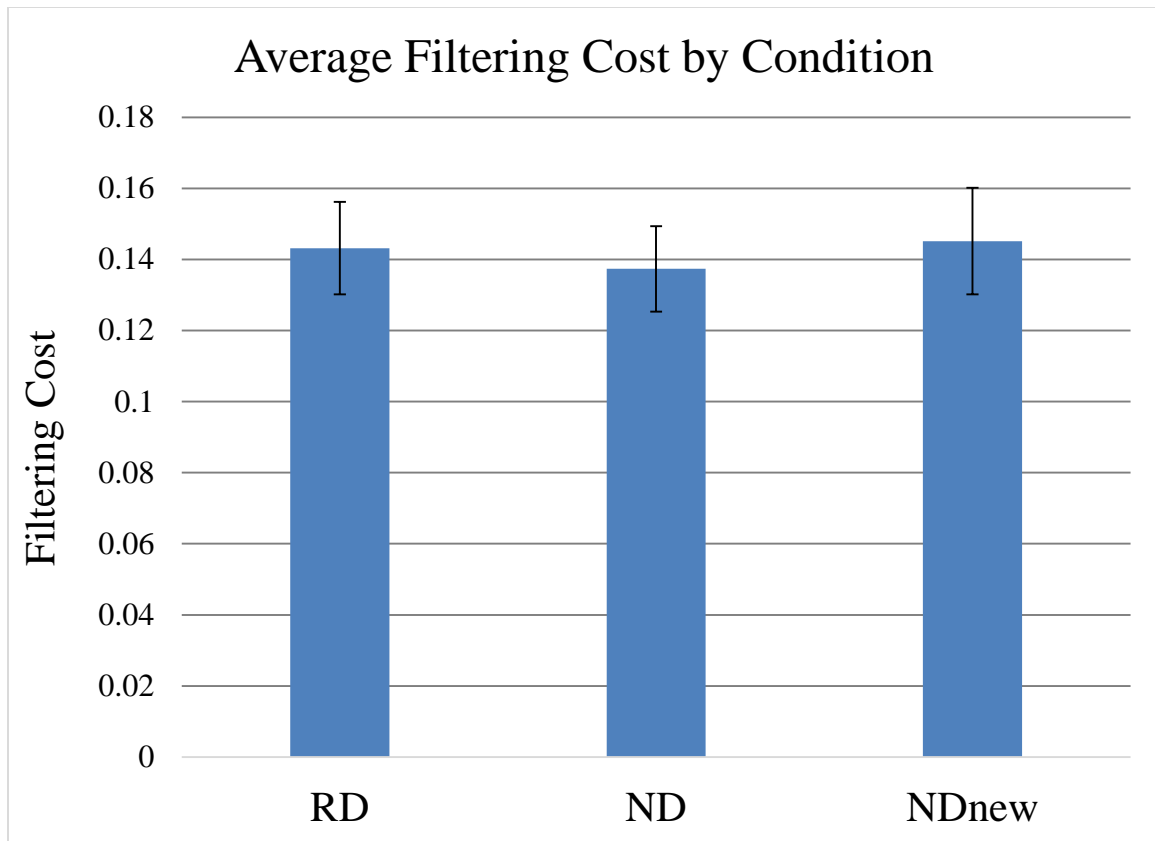**Figure3.** Average filtering cost by condition. There were no significant differences across condition in filtering inefficiency into working memory.

Filtering Cost over Time

In an exploratory analysis we tested for the possibility that responses to the previously rewarded distracter may have extinguished over time in the test phase. We divided trials into three different time bins across the task (Early = trials 1-102, Middle = 103-204, Late = 205-306) and calculated filtering cost scores for RD, ND, and NDnew for each bin. A repeated measures ANOVA was conducted with both Time and Condition as within subject factors. There was no significant main effect of Condition [$F(2,110) =$ .160, $p = .853$], or Time [$F(2, 110) = 2.226$, $p = .113$. This indicates there are no significant differences in filtering efficiency across condition or over the course of the task. Finally there was no significant interaction between Condition and Time [$F(4,220)$

= .230, p = .921.

Filtering Cost by Time
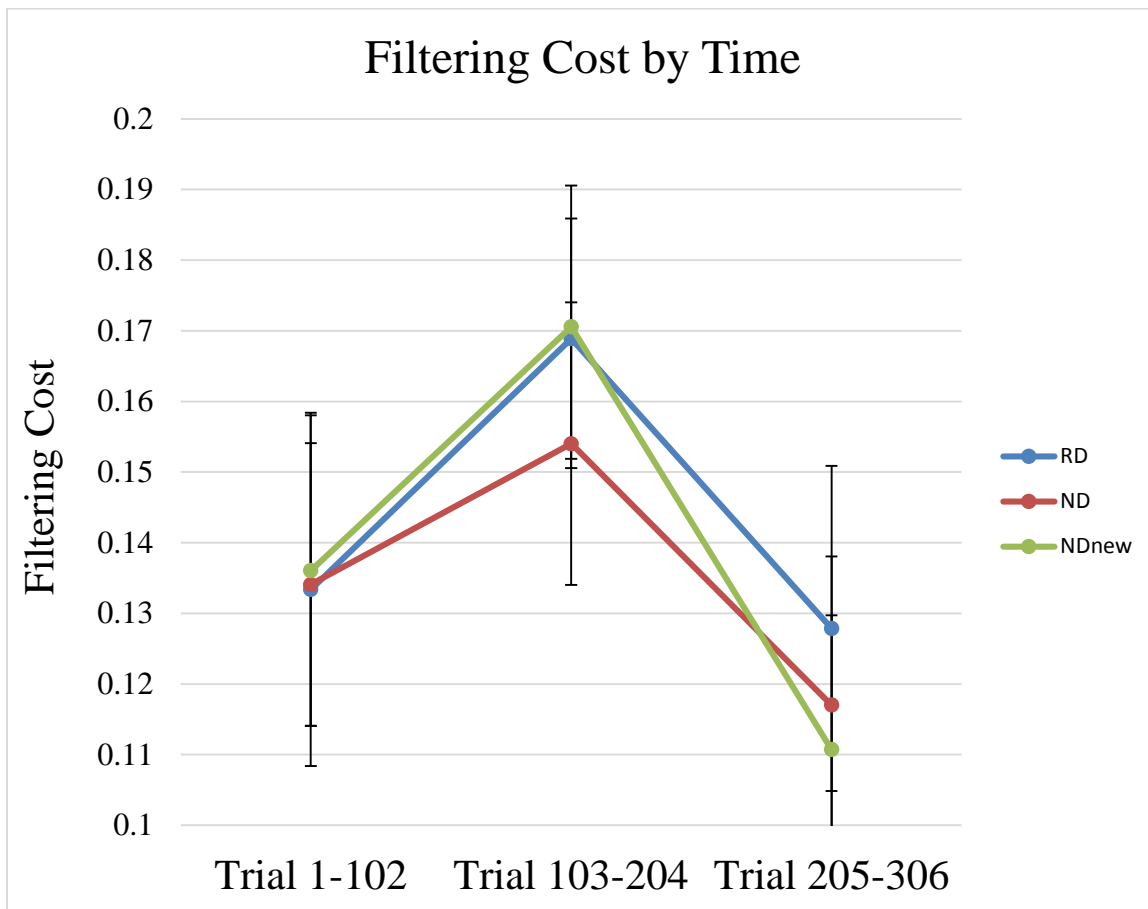
Figure4. Average filtering cost scores by time bin for each condition. There were no significant main effects of time or condition, or a significant interaction of time by condition.

Individual Differences in the Presence of Reward Distracters

Table 1 shows Pearson correlations for each measure of individual differences (BIS11, BAS, Sensitivity to Reward, and working memory capacity). There was a significant negative correlation between filtering cost scores in the RD condition and sensitivity to reward as measured by the SR scale in the SRSPQ. This correlation indicated that those who scored higher on the Sensitivity to Reward scale were more efficient at filtering out reward distracters (condition RD). There were no significant correlations between RD filtering cost scores and scores on the BIS11 impulsivity scale

or BAS. There were also no significant correlations between K scores on the BIS11,

BAS, or SR scale in any of the distracter conditions (see Table 1 below).

Measure	N	K Scores				Filtering Cost Scores			
		RD	ND	NDnew	ND-RD	RD	ND	NDnew	ND-RD
BIS 11	39	.019				.197			
BAS Total	52	.092				-.200			
Sensitivity to Reward	56	.177				**-.307***	.251	-.211	
WM Capacity	55	**.309***	.217	.177	-.058				-.027
*p <.05									

Table1. **Individual Differences**. Pearson correlations for BIS11, BAS, Sensitivity to Reward, and working memory capacity. Sensitivity to Reward was negatively correlated with filtering cost for RD. Working memory capacity was positively correlated with K for RD.

To examine whether greater working memory capacity was associated with better filtering of reward distracters, we took a difference score between ND and RD (ND-RD) and correlated that value with individual working memory capacity as measured by Pashler's K. We found no significant relationships between these differences scores in K or filtering cost and working memory capacity. We then correlated K scores for each condition with working memory capacity and found a significant positive correlation between K scores in RD and working memory capacity. There was no significant relationship between K scores in ND or NDnew and working memory capacity (see table 1). This may indicate that an individual's working memory capacity is important for remembering targets particularly in the presence of a reward distracter.

Discussion

  The purpose of this study was to test whether the presence of a task-irrelevant distracter stimulus that was previously associated with reward would impair working memory performance in two ways. First, we predicted that filtering of relevant information into working memory would be impaired. Second, we predicted that working memory capacity for target items would be lower. The results of the current study did not support the predictions. Although the presence of distracters impaired working memory performance, we did not find any support to show that previously rewarded distracters affected performance more than neutral distracters.

  The findings of the current study are not consistent with what would be predicted based on the hypothesis that reward captures attention in an involuntary bottom-up fashion (Anderson et al., 2011; Hickey & van Zoest, 2012), which was the primary hypothesis behind this work at the time I proposed it. However, since the proposal of the current study Gong and Li (2014) published a study examining the influence of irrelevant reward on working memory using a similar approach, and their findings are consistent with what we found. In a similar task, they found improved working memory performance when a probe item was presented in the previously rewarded color. However, they found no impairment in working memory performance of a probed stimulus when a previously reward stimuli was also presented in the memory array, inconsistent with the attentional capture hypothesis.

  In light of these findings Gong and Li (2014) posited that there may be multiple ways in which reward influences attention. While, it has been demonstrated that one influence is through attentional capture of reward stimuli (Anderson et al., 2011;

Anderson & Yantis, 2012), another influence may be through enhanced early perceptual processing. Although several studies have argued that the distracting effect of reward is primarily due to attentional capture (Anderson et al., 2011; Anderson & Yantis, 2012; Hickey et al., 2010; Theeuwes & Belopolsky, 2012), Gong and Li (2014) did not find evidence to support this hypothesis. In their experiment three, participants completed a training phase and then a working memory test phase like the current study. However, in the test phase they presented all items (rather than just distracters) in either the high reward, low reward, or control color. They still found there was greater working memory improvement in a change detection task in which all stimuli, targets and distracters, were presented in the high reward color over the low reward and a control color. Since distracters and the target were all presented in the same color, attentional capture alone could not explain the improved influence on working memory performance. Therefore, the findings of the current study may also lend evidence to suggest that the influence of reward stimuli on visual attention may not be entirely due to attentional capture but may be modulatory through feature-based attention (Gong & Li, 2014).

In addition, the current study was in part based on work investigating the influence of threat distracters; however, reward and threat may have different attentional effects. Gong and Li (2014) argue that reward may influence attention by enhancing the representation of task-relevant stimuli in working memory, but in contrast to what has been found with task-irrelevant threat (Bishop, 2007; Stout et al., 2013), task irrelevant reward does not necessarily impair task-relevant representations. The potential differential effects of reward and threat on selective attention may reflect the different neural circuitry instantiating detection of threat and reward. Detection of threat is

dependent on amygdala-prefrontal circuitry (Bishop, 2007; Shechner et al., 2012), while detection of reward typically involves frontostriatal circuits (Frank & Fossella, 2010; Shechner et al., 2012). In addition, this system may interact with regions implicated in attentonal control to boost these processes (Engelmann, Damaraju, Padmala, & Pessoa, 2009), interestingly, activation of the basal ganglia-PFC circuitry has also been associated with better filtering of distracters (McNab & Klinberg, 2008). It is possible that even though this circuit responds to reward, the activation of frontostriatal circuitry also boosts attentional filtering into working memory. This may be an important factor in understanding why irrelevant threat may have privileged access to working memory stores while reward does not.

We also examined the influence of individual differences in reward sensitivity, impulsivity, and working memory capacity on filtering of reward distracters into working memory. In contrast with our hypothesis, we found that those higher in sensitivity to reward actually were better able to filter our reward distracters than those low in sensitivity to reward. Although we predicted that those sensitive to reward may be more susceptible to attentional biases to previously rewarded stimuli (even in a non-rewarded task), it may be possible that the presence of a reward cue, although task-irrelevant, may have increased cognitive control in those high in sensitivity to reward. This is consistent with previous working memory studies that have demonstrated those high in trait sensitivity to reward were better able to optimize their performance in a rewarded task (Jimura, Locke, & Braver, 2010). This is hypothesized to be due to a shift in proactive cognitive control evident by greater PFC activation in reward contexts (Braver, 2012). In this case, these individuals were better able to filter out reward distracters and attend to

the current task. We also found some evidence to suggest that an individual's working memory capacity is important in remembering targets in the face of distracters. High working memory capacity was associated with better working memory capacity for target items in the face of distracters, but only when a reward distracter was present. Previous research has suggested that those low in working memory capacity are more susceptible to attentional capture to bottom-up salient stimulus features (Fukuda & Vogel, 2009) as well as to previously rewarded distracters (Anderson et al., 2011). Perhaps, those high on WM capacity are better able to inhibit the influence of salient reward distracters. It is important to point out that we did not correct for family-wise error in our analyses of individual differences, but these results indicate the need for feature investigation to replicate these important individual differences in reward processing.

Although, there may be evidence to suggest that attentional capture of task-irrelevant reward does not lead to impairment in working memory performance (Gong & Li, 2014), more research is necessary to support this conclusion. Even though we did not currently find a distracting effect of irrelevant reward, there are several reasons why the current study may not have been optimal to detect the effect of a reward distracter on working memory. The amount of cognitive demand placed on participants in the current task was higher than that of Anderson et al. (2011) since participants also had to encode and maintain two items in working memory, rather than detecting a singleton in an array. Gong and Li (2014) had a load of 8 items over the delay, which is much higher than the current study. Prior research has demonstrated that increasing working memory load increases the impact of distracters in a separate task (de Fockert, Rees, Frith, & Lavie., 2001; Lavie, de Fockert, & Viding, 2004; Lavie & de Frockert, 2005). It is possible that

the load on working memory increased the impact of distracters to a point that there was no longer an effect of the valence of the distracter. If cognitive load in fact decreases the impact of attentional bias of a particular valence that could explain why Gong and Li (2014) and the current study did not find evidence of attentional capture. Finally, we also did not assess how well the contingencies between the stimulus and reward were learned in the training phase. It may be important to assess both explicitly and implicitly whether participants made the necessary reward associations. Indeed there is evidence to suggest that conscious and unconscious processing of reward cues differentially impacts maintenance of goal-relevant information in working memory (Zedelius, Veling, & Aarts, 2011).

Future Directions

The exact mechanism involved in reward's influence on visual selective attention is still not well understood. Although several studies have demonstrated the impact of reward on attention, the attentional capture hypothesis may not be able to entirely explain the influence reward associated features have on attention. The current study and previous studies (Gong & Li, 2014) have failed to demonstrated the same impairment in working memory performance with reward distracters present that has been found in threat distracters (Sessa, Luria, Gotler, Jolicoeur, & Dell'Acqua, 2011; Stout et a., 2013). Therefore, unlike threat, it is possible that irrelevant reward does not generally interfere with working memory processes. Neuroimaging studies would be useful in clarifying the common and distinct mechanisms underlying visual selection and working memory in the face of task-irrelevant threat and reward.

In addition, future research should attempt to characterize individual differences

that may moderate selective attention to reward stimuli. So far research has demonstrated individual differences related to selective attention to irrelevant reward in working memory capacity (Anderson et al., 2011), trait impulsivity (Anderson et al., 2011), age (Roper, Vecera, & Vaidya, 2014), and depression (Anderson, Leal, Hall, Yassa, & Yantis, 2014). In the current study, we found some evidence to suggest that individual differences such as working memory capacity and reward sensitivity may impact ability to filter irrelevant reward stimuli. Therefore, further research may be able to elucidate how reward can be more or less distracting based on individual differences and clinical presentations.

In summary, although previous research has demonstrated a robust attentional bias toward previously rewarded stimuli, little is known about how this attentional bias impacts down-stream processing. If attentional selection acts as the gatekeeper of attention (Awh et al., 2006) then some decision must be made about how to deal with these reward stimuli that are competing for attentional resources. Previous research suggests it is not merely ignored or gated from working memory (Gong & Li, 2014), and further research may elucidate how these cues influence on going task behavior.

References

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences*, *108*(25), 10367-10371.

Anderson, B.A. (2013). A value-driven mechanism of attentional selection. *Journal of vision*, *13*(3), 1-16.

Anderson, B. A., & Yantis, S. (2013). Persistence of value-driven attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(1), 6-9.

Anderson, B. A., Leal, S. L., Hall, M. G., Yassa, M. A., & Yantis, S. (2014). The attribution of value-based attentional priority in individuals with depressive symptoms. *Cognitive, Affective, & Behavioral Neuroscience*, 1-7.

Awh, E., Vogel, E. K., & Oh, S. H. (2006). Interactions between attention and working memory. *Neuroscience*, *139*(1), 201-208.

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: a failed theoretical dichotomy. *Trends in cognitive science*, *16*(8), 437-443.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*(1), 1-29.

Bannerman, R. L., Milders, M., & Sahraie, A. (2010). Attentional bias to brief threat-related faces revealed by saccadic eye movements. *Emotion*, *10*(5), 733-738.

Bishop, S. J. (2007). Neurocognitive mechanisms of anxiety: an integrative account. *Trends in cognitive sciences*, *11*(7), 307-316.

Bishop, S. (2008). Neural mechanisms underlying selective attention to threat. *Annals of the New York Academy of Sciences*, *1129*, 141-152.

Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in cognitive sciences*, *16*(2), 106-113.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS Scales. *Journal of personality and social psychology*, *67*(2), 319-333.

Corbetta, M., & Shulman, G. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 215-229.

Cowan, N. (2001) The magical number 4 in short-term memory: a reconsideration of mental storage capacity. *Behav. Brain Sci*. 24, 87-185.

Cowan, N. (2005). *Working memory capacity*. Psychology press.

de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science*, *291*(5509), 1803-1806.

Della Libera, C., & Chelazzi, L. (2006). Visual selective attention and the effects of monetary rewards. *Psychological Science*, *17*(3), 222-227.

Della Libera, C., & Chelazzi, L. (2009). Learning to attend and to ignore is a matter of gains and losses. *Psychological Science*, *20*(6), 778-784.

Dolcos, F., & McCarthy, G. (2006). Brain systems mediating cognitive interference by emotional distraction. *The Journal of Neuroscience*, *26*(7), 2072-2079.

Engelmann, J. B., Damaraju, E., Padmala, S., & Pessoa, L. (2009). Combined effects of attention and motivation on visual task performance: transient and sustained motivational effects. *Frontiers in human neuroscience*, *3*, 1-17.

Frank, M. J., & Fossella, J. A. (2010). Neurogenetics and pharmacology of learning, motivation, and cognition. *Neuropsychopharmacology*, *36*(1), 133-152.

Fortier-Gauthier, U., Dell'Acqua, R., & Jolicœur, P. (2013). The "red-alert" effect in visual search: Evidence from human electrophysiology. *Psychophysiology*,*50*(7), 671-679.

Fukuda, K., & Vogel, E. K. (2009). Human variation in overriding attentional capture. *The Journal of Neuroscience*, *29*(27), 8726-8733.

Goldman-Rakic, P. (1996). Regional and cellular fractionation of working memory. *Proceedings of the National Academy of Sciences, 93*(24), 13473-13480.

Gong, M., & Li, S. (2014). Learned reward association improves visual working memory. *Journal of Experimental Psychology: Human Perception and Performance, 40*(2), 841-856.

Hickey, C., Chelazzi, L., & Theeuwes, J. (2010). Reward changes salience in human vision via the anterior cingulate. *The Journal of Neuroscience*, *30*(33), 11096-11103.

Hodsoll, S., Vinding, E., & Lavie, N. (2011). Attentional capture by irrelevant emotional distractor faces. *Emotion, 11,* 346–353.

Hickey, C., & van Zoest, W. (2012). Reward creates oculomotor salience. *Current Biology*, *22*(7), R219-R220.

Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences*, *107*(19), 8871-8876.

Kiss, M., Driver, J., & Eimer, M. (2009). Reward priority of visual target singletons modulates event-related potential signatures of attentional selection. *Psychological Science*, *20*(2), 245-251.

Krebs, R. M., Boehler, C. N., & Woldorff, M. G. (2010). The influence of reward associations on conflict processing in the Stroop task. *Cognition*, *117*(3), 341-347.

Kristjánsson, Á., Sigurjónsdóttir, Ó., & Driver, J. (2010). Fortune and reversals of fortune in visual search: Reward contingencies for pop-out targets affect search efficiency and target repetition effects. *Attention, Perception, & Psychophysics*, *72*(5), 1229-1236.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General*, *133*(3), 339.

Lavie, N., & De Fockert, J. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin & Review*, *12*(4), 669-674.

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279-281.

McNab, F., & Klingberg, T. (2007). Prefrontal cortex and basal ganglia control access to working memory. *Nature neuroscience*, *11*(1), 103-107.

Miller, E. K. (2000). The prefontral cortex and cognitive control. *Nature reviews neuroscience*, *1*(1), 59-65.

Pashler, H. (1988). Familiarity and visual change detection. *Attention, Perception, & Psychophysics*, *44*(4), 369-378.

Patton JH, Stanford MS, Barratt ES. Factor structure of the Barratt impulsiveness scale. *J Clin Psychol*. 1995;51(6):768-74.

Pessoa, L., & Engelmann, J. B. (2010). Embedding reward signals into perception and cognition. *Frontiers in Neuroscience, 4*, 10.3389/fnins.2010.00017. eCollection 2010.

Qi, S., Zeng, Q., Ding, C., & Li, H. (2013). Neural correlates of reward-driven attentional capture in visual search. *Brain research*, *1532*, 32-43.

Roper, Z., Vecera, S., & Vaidya, J. (2014). Value-driven attentional capture resists extinction in adolescence. *Journal of Vision*, *14*(10), 505-505.

Sessa, P., Luria, R., Gotler, A., Jolicœur, P., & Dell'Acqua, R. (2011). Interhemispheric ERP asymmetries over inferior parietal cortex reveal differential visual working memory maintenance for fearful versus neutral facial identities. *Psychophysiology*, *48*(2), 187-197.

Shechner, T., Britton, J. C., Pérez-Edgar, K., Bar-Haim, Y., Ernst, M., Fox, N. A., Leibenluft, E., & Pine, D. S. (2012). Attention biases, anxiety, and development: toward or away from threats or rewards?. *Depression and anxiety*, *29*(4), 282-294.

Stout, D. M., Shackman, A. J., & Larson, C. L. (2013). Failure to filter: Anxious individuals show inefficient gating of threat from working memory. *Frontiers in Human Neuroscience*, *7*, 1-10.

Theeuwes, J. (2010). Top–down and bottom–up control of visual selection. *Acta psychologica*, *135*(2), 77-99.

Theeuwes, J., & Belopolsky, A. V. (2012). Reward grabs the eye: Oculomotor capture by rewarding stimuli. *Vision research*, *74*, 80-85.

Torrubia, R., Avila, C., Moltó, J., & Caseras, X. (2001). The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. *Personality and Individual Differences*, *31*(6), 837-862.

Vogel, E., McCollough, A., & Machizawa, M. (2005). Neural measures reveal individual differences in controlling access to working memory. *Nature*, *438*(7067), 500-503.

Vogel, E., & Machizawa, M. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature*, *428*(6984), 748-751.

Vuilleumier, P., & Huang, Y. M. (2009). Emotional attention uncovering the mechanisms of affective biases in perception. *Current Directions in Psychological Science*, *18*(3), 148-152.

Zedelius, C. M., Veling, H., & Aarts, H. (2011). Boosting or choking–How conscious and unconscious reward processing modulate the active maintenance of goal-relevant information. *Consciousness and cognition*, *20*(2), 355-362.