“CAN’T LET IT GO”: THE PERSISTENCE OF CUE-DRIVEN REWARD-SEEKING DESPITE GOAL-RELATED CONSEQUENCES.

by
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Abstract

Humans possess an amazing repertoire of higher-order capacities for planning and pursing goals. However, everyday life requires continuous juggling of multiple priorities across various time scales. Given limited cognitive resources to attend to multiple priorities, over-attending to a given priority often comes at the expense of under-attending to other priorities. Compulsive over-prioritization of a specific stimulus or state is one of the hallmark signs of addiction. Once an individual progresses in the trajectory of addiction, substances and the cues that predict substance availability maintain a powerful hold over attention and behavior even after extended periods of abstinence; it appears they “can’t let it go.”

Numerous measurement tools have been employed in cognitive psychology and neuroscience research to assess correlates and causal factors linked to addictive tendencies. This dissertation examines the reliability and validity of selective attention paradigms that have been adapted to study biased attentional priorities in humans, investigates the translational relevance of paradigms designed to measure incentive salience attribution in animals, and describes a novel method for measuring biased priorities in the management of multiple goals in dynamic environments. First the reliability and validity of the value-driven attentional capture (VDAC) paradigm was assessed. Across several experiments, poor reliability and multiple indices of poor validity were observed, suggesting this measure is not suitable for estimating individual differences or testing the effectiveness of intervention techniques. Next, the translational relevance of a Pavlovian conditioning task commonly used to train animals to associate rewards with cues and measure incentive salience attribution was assessed using an adapted eye-tracking paradigm. The majority of participants dwelled on and vigorously interacted with reward-predictive cues, indicating cues acquired incentive salience. The degree to which they interacted with the reward-predictive cues was related to the magnitude of attentional capture by these cues in a subsequent selective attention task. Finally, a novel paradigm for assessing behavioral tendencies to pursue reward opportunities, despite the accumulation of negative consequences, was tested. In general, participants persistently attempted to pursue rewards, even when reward-seeking behaviors had negative consequences for progress toward the overarching goals of the task. However this behavior was modulated by negative consequence-related feedback.

The work presented in this dissertation has implications for the development of prevention, intervention and treatment techniques that could be individualized to address a multitude of addictive behaviors. Individuals with a history of addiction commonly report desire to change behaviors that have become maladaptive, but frequently relapse into past behavioral patterns. Prevention tools that utilize dynamic outcome feedback may help individuals recognize the slow build of consequences that occur when substance abuse conflicts with goals, before later stages of addiction have taken hold.

Primary Reader and Advisor: Susan Courtney

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Dedication

This dissertation is dedicated to my wife, Stephanie Durakis,
for her constant support, love, and encouragement.

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Chapter 1

Introduction

Despite the amazing repertoire of higher-order capacities that humans possess for planning and pursing goals, selecting goal-directed behaviors in the face of conflicting gratification opportunities can be extremely challenging. Whether it’s passing up a free doughnut to maintain a diet or running errands rather than watching Netflix, this type of conflict arises in a variety of everyday situations. A particularly problematic example of difficulty in resolving this type of conflict is evident in the pattern of relapse in drug addiction, where individuals tend to fall back into drug-seeking behaviors regardless of firmly held goals to remain abstinent (Smyth, Barry, Keenan, & Ducray, 2010). The relapse rates for substances that have high risks of devastating short-term consequences (e.g. over-dose) and long-term effects (e.g. general deterioration of health) have contributed to the classification of addiction as a major public health crisis (Rudd, Seth, David & Scholl, 2016). When it comes to the cycle of addiction, relapse is the norm rather than the exception (NIDA, 2018).

This review discusses role of value-associated cues in conflicts that arise between goal-driven behavior and reward-seeking behavior. Theories of reward learning, attention, and cognitive control are discussed in the context of basic brain-cognition-behavior as well as compulsive disorders such as addiction. The effects of reward on cognition and behavior are extensively studied throughout all major areas of psychological research. Convergence of information gleaned from the sometimesdisparate areas of research is critical for the development of successful intervention and prevention techniques.

1.1 "Let go or be dragged": Persistent responsivity to value-associated cues.

"Let go or be dragged"- Zen Proverb

One of the key predictors of relapse is exposure to drug-associated cues (Beardsley et al., 2012). Lasting associations can form between stimuli and substances of abuse, even after a brief experience of pairing (Hogarth et al., 2015). When these stimuli are then encountered again later on, they can capture attention, trigger cravings and lead to substance-seeking behaviors (Field & Cox, 2008). Unfortunately, the tendency to selectively attend to substance-related cues lasts far beyond initiation of attempts to remain abstinent and can continue to create conflict for goal-relevant behaviors. After seemingly successful stints in a rehabilitation program, simply returning home to an environment saturated with familiar substance-related cues and contexts commonly leads individuals to revert to drug-seeking habits (Tiffany, 1990). Cues can maintain a long-lasting hold over attention and behavior, remaining "motivational magnets," despite the accumulation of negative consequences (Berridge, Robinson & Aldridge, 2009).

Attention bias for previously relevant cues is not, however, specific to substances of abuse. Biases have been observed for a myriad of self-relevant information domains. People with chronic pain show biases toward pain-related information (Schoth & Liossi, 2012); people with insomnia show biases toward images depicting daytime sleepiness (Jansson-Frojmark et al. 2013), and the list goes on. Like biased attention toward drug-cues, these biases have the potential to interfere with goal-relevant attentional control by promoting selection of associated information and prompting rumination, perseveration and distractibility. However, behavioral interventions for maladaptive attentional biases, such as attentional bias modification, have been met with limited success (Emmelkamp, 2012, Mogg et al., 2017). The interventions that do show change in bias magnitude in laboratory settings often fail to generalize to changes in cravings or behavior following exposure to cues (Christiansen, Shoenmakers & Field, 2015).

The following sections discuss literature related to the acquisition of cue-value associations, the attribution of incentive salience to these cues, and the influence value-associated cues have on selective attention. Learning about the predictors of rewards and other sources of value in the external world is a strong determinant of behavior. Following experience of the pairing of value and cues, the cues themselves can come to develop motivational value and invigorate behavior and complex emotional states. Biases in attentional priority towards these stimuli can outlast goals and current relevance.

1.1.1 *Connecting:* Learning about value-associated cues

The ability to obtain and maintain information about where, when and why valuable stimuli are present in the environment is critical for optimization of the time and effort expended on their pursuit. Humans and non-human animals are highly adept at learning associations between appetitive or aversive stimuli and the cues that signal their availability. Early studies of classical conditioning demonstrated that repeated presentation of a cue (e.g. bell sound) that signaled the upcoming presentation of an appetitive stimulus (e.g. food), could come to reliably drive anticipatory reflexes (e.g. salivation) upon presentation of the cue (Pavlov, 1927). Whereas classical, or Pavlovian, conditioning is centered on learning associations between two stimuli, operant, or instrumental, conditioning is centered on learning associations between behaviors and outcomes (e.g. lever pressing and food delivery; Skinner, 1938). Based on Thorndike's (1898) *Law of Effect* principles that behaviors that produce positive or negative consequences are likely to be repeated or suppressed, respectively, studies of reinforcement learning have produced a wealth of information on the impact of schedules of reinforcement on behavior, (Ferster & Skinner, 1957), attention (Grossberg, 1975) decision-making and learning (Niv, 2009).

Learning is a powerful regulator of motivated behavior and is reflected in plasticity processes in the brain. Long-term potentiation (LTP) is the leading cellular model for learning and associative memory. Following synchronized patterns of firing, the strengthening of synaptic connections occurs between neurons resulting in more efficient communication (Bliss & Lomo, 1973). Since it's seminal publication in 1973, thousands of papers have been published on LTP, leading to a better understanding of associative learning and memory (Nicoll, 2017). Dopamine plays a critical role in long-term potentiation at hippocampal-prefrontal cortex synapses (Gurden, Takita & Jay, 2000) and because drugs of abuse directly or indirectly influence dopamine within the reward-circuitry of the brain (Koob, Sanna & Bloom, 1998), understanding of how drugs tap into normal learning mechanisms has been the focus of much research over the last several decades (Hyman, Malenka & Nestler, 2006).

The ability to learn predictive relationships between stimuli in the environment facilitates the maximization of rewarding stimuli and minimization of aversive stimuli. This type of associative learning is also reflected in measures of neural plasticity. For instance, Schultz and colleagues showed that early on in conditioning protocols, the spiking of dopamine neurons in the midbrain are temporally associated with presentation of naturally rewarding stimuli (e.g. food; Ljungberg, Apicella, Schultz, 1992). However, upon repeated exposure to the pairing of natural reward with a predictive cue, the timing of the release of dopamine shifts and occurs with the presentation of the cue rather than the presentation of the natural reward (Schultz, Apicella, and Ljungberg 1993). In normal circumstances, brain dopamine systems often respond as though they are responding to reward prediction error (RPE), or errors in the prediction of expected rewards vs. outcomes (Schultz, Dayan & Montague, 1997). However, even animals that do not have dopamine (based pharamacological blockade or lesion; Berridge & Robinson, 1998) can exhibit preferences for hedonic stimuli, indicating that RPE cannot fully account for the internal representation of rewarding states or stimuli. This finding, among other corroborating dopamine-depletion findings, lead to the incentive sensitization theory that posits that dopamine is critical for the attribution of incentive salience to the neural representations of reward-related stimuli.

1.1.2 *Projecting:* Attributing incentive salience to cues

The attribution of incentive motivational value, or incentive salience, to environmental stimuli allows their presentation to evoke complex emotional and motivational states (Stewart et al., 1984). Stimuli that have been imbued with incentive salience, referred to as incentive stimuli, acquire three key properties: 1) they are attractive and elicit approach 2) they act as conditioned reinforcers to be desirable in their own right and 3) they are able to energize ongoing reward-seeking actions (Cardinal et al., 2002, Berridge 2000). There is considerable variation in the extent to which individuals acquire incentive salience attribution for Pavlovian-conditioned cues (Fitzpatrick et al., 2013). In the autoshaping paradigm (Brown & Jenkins 1968) commonly used to measure incentive salience attribution, a lever is presented randomly to rats for an 8-second period and then retracted and a sucrose pellet is delivered into a nearby food cup. For some animals, referred to as "sign-trackers," the lever-cue reliably elicits approach and invigorates behaviors that produce presentation of the lever-cue alone (Hearst & Jenkins, 1974). However, for some animals, referred to as "goal-trackers," the lever-cue does not become an incentive stimulus, as goal-trackers do not approach the lever-cue nor do they work for lever-presentation (Boakes, 1977). The study of sign- versus goal-tracking is of great importance in the context of addiction, as the attribution of incentive salience to reward-paired cues leaves sign-trackers susceptible to relapse in the face of previously drug-associated stimuli (Flagel, Akil & Robinson, 2009; Robinson et al., 2014; Pitchers, Sarter & Robinson, 2018).

The incentive sensitization theory of addiction (Robinson and Berridge, 1993) suggests that chronic drug use sensitizes individuals towards increased salience of both the drug and drug-related stimuli. This process promotes greater "wanting" of drugs and is thought to be involved in compulsive use and poorly regulated control in later stages of addiction, despite decreases in hedonic "liking" over time (Berridge, Robinson & Aldrigde, 2009). Drugs of abuse tend to sensitize the mesolimbic dopamine system; particularly following repeated exposure (Robinson & Becker, 1986). Sensitization promotes hyper-reactivity to both drugs and the cues that they are associated with. The effects this sensitization has on motivated behavior has been a focus of intense investigation in recent years, and more recently, has been extended to investigations on attentional selection in healthy human research participants.

1.1.3 *Selecting:* Value-based attentional priority

Given that typical environments include far more information than can be processed at once, attention selects a subset of the vast amount of potential input for the allocation of processing resources. Selective attention determines the likelihood that information will receive preferential representation in the brain and influence learning, memory and behavior (Desimone & Duncan, 1995; Duncan, 1996; Desimone, 1998). When salient stimuli are present in the world around us, odds in the competition for cognitive processing resources are stacked in their favor. At basic levels of visual processing, prioritization of stimuli that stand out in color, shape, size or movement occurs (Yantis, 1993). While these processes take place automatically, priorities are also shaped by goals, experience and value (Bacon & Egeth, 1994).

Individuals with a history of addiction commonly exhibit attentional biases toward stimuli associated with substances of abuse. This pattern has been extensively studied in laboratory settings and theoretical models posit that biased attention is a key characteristic of addiction (Field and Cox, 2008). When substance-related cues are present in the environment, goals (e.g. abstinence, health & wellness) and goal-directed behaviors can become derailed despite the observer's intentions (Marissen et al., 2007). Common narratives of how this could manifest in the real world take the gist of a person walking down the street on the way to buy groceries, encountering a bar sign, and abandoning their grocery-related goals to pursue alcohol. Enhanced priority for substance-related stimuli bias selective attention, and selection can trigger a cascade of intrusive thoughts of the substance, competition for elaboration resources in working memory, craving, substance-seeking behavior and ultimately use (Kavanagh et al., 2005).

Attempts to model these real world attention biases in laboratory settings have largely focused on the immediate, short-term, implicit effects of substance-related cues on selective attention. The paradigms utilized often focus on sub-second biases in task performance, either facilitating responses when a target replaces a relevant cue in spatial location (Dot-probe task; Ehrman et al., 2002) or delaying responses during conflict resolution (Stroop task; Cox, Farardi & Pothos, 2006) or search for task-relevant stimuli (Visual search). For example, a phenomenon known as value-driven attentional capture (VDAC) is characterized by the rapid orienting of attention toward cues previously associated with reward, even when the cue-reward association is no longer valid or task-relevant (Anderson, Laurent & Yantis, 2011). The standard paradigm used to measure VDAC includes a reward-cue association phase, where colored stimuli are repeatedly paired with monetary rewards, followed by a distraction testing phase, where the previously rewarded stimulus is present, but task-irrelevant and no longer rewarded. Participants are typically slower to respond to the task-relevant targets when a previous reward cue is present compared to when no distractor cue is present. This pattern is taken to reflect an involuntary mechanism of attentional selection that is uniquely value-driven (Anderson et al., 2012) and is thought to reflect the same cognitive processes as addiction-related attentional biases (Anderson, 2016).

One of the motivations behind the development of the VDAC experimental paradigm was to provide a controlled method of inducing and measuring attention biases in the laboratory that were independent of long-term reward learning history. One of the difficulties of studying attention bias in individuals addicted to substances of abuse is that each person has learned, over months or years, to associate the reward of the drug with a unique set of stimuli and contexts. It was thought that in the same way a syringe can capture attention and elicit cravings in an abstinent individual with a history of heroin addiction, the VDAC paradigm showed that colored shapes that were previously paired with monetary rewards could capture attention as well (Anderson, 2016). However, there are two classes of attention capture, described as "explicit attentional capture" and "implicit attentional capture" (Simons, 2000). The former occurs when a salient stimulus draws awareness, while the latter occurs when a salient, task-irrelevant stimulus affects performance on another task, regardless of awareness. These definitions of attention capture often conflated throughout the literature (Most & Simons, 2001) and visual attention task-paradigms that are designed to measure implicit capture are frequently described as being related to explicit capture.

Individuals with addiction history are acutely aware of the relationship between syringes, drugs, and their effects. In contrast, across the VDAC literature it has been reported that the short-term implicit association between colors and monetary value in the VDAC paradigm, does not drive explicit learning for the majority of participants. For instance, a study that measured VDAC in individuals with a history of addiction and controls reported that approximately 80% of participants did not demonstrate explicit awareness of the relationship between color and value during training (Anderson, Faulkner, Rilee, Yantis, & Marvel, 2013).

Despite findings that the clinical relevance of VDAC (DiBartolo, Gmeindl & Courtney, submitted) and other attentional bias paradigms (Christianson, Schoenmakers & Field, 2015) may be "less than meets the eye," it is generally accepted that attention guides information selection to maximize rewards, minimize costs and reduce uncertainty (Gottlieb et al. 2014). Reward-based learning can alter attentional priority maps even after brief instances of pairing (Chelazzi et al., 2014). The following section discusses the cognitive control of selection, maintenance, and updating of information as it relates to managing multiple currently relevant goals, value-based decision-making and the ability to adapt to changes in goals or the environment.

1.2 Managing multiple goals in dynamic environments

Successful behavior in dynamic environments requires both flexibility and stability to meet current demands. Flexibly updating task-relevant representations based on important novel information is critical, but the ability to maintain stable task-relevant representations in the face of irrelevant distractions is also necessary. For example, while focusing on the road during driving it is imperative to flexibly update attention in response to potential obstructions, but to also maintain stable focus in the face of billboards and other driving-irrelevant information. Imbalance in either direction could result in negative outcomes: if we are too flexible, we may become distracted; if we are too stable, we may be unresponsive to new information. Individuals with substance-use disorders exhibit deficits in prefrontal cortex (PFC) dependent executive process such as working memory, decision-making and inhibitory control (Bechara & Martin, 2004). Whether these deficits play a role in the initiation of risky behaviors prior to addiction and/or exacerbate maladaptive behavioral problems once use has transferred to abuse/later stages is a major topic of interest across cognitive psychology and neuroscience domains.

1.2.1 *Directing:* Flexibility and stability of cognitive control

Cognitive control is the ability to flexibly adjust thoughts and behaviors to meet internal goals and external demands. Acting or responding to a stimulus or state involves multiple processing stages (e.g., Sternberg, 1969). One of the prominent theories regarding cognitive control mechanisms is the dual-mechanisms of control framework (Braver, Gray & Burgess, 2007). According to this framework, “proactive control” maintains goal-relevant representations in an active, preparatory manner, whereas “reactive control” is responsive to detection of events that trigger retrieval of goal-relevant representations. Biases in proactive vs. reactive control may play a role in intra-individual, inter-individual, and between-groups differences (Braver, 2012).

The prefrontal cortex (PFC) is critical for the active representation of contexts, goals and plans and damage to this area can cause deficits in the ability to maintain focused attention (Milner, 1963). The dopamine system is critical for appropriately updating the contents of active PFC maintained representations (Braver & Cohen, 2000). Like reward learning, cognitive control also depends on dopaminergic systems in the brain (Cools & D’Esposito 2011). Particularly, the dopaminergic system exhibits a U-shaped dose-response curve, which leads to specific dosages of dopaminergic drugs producing optimal performance on working memory tasks (Arnsten et al. 1997). High PFC DA levels (and relatively low striatum DA) are associated with stability in control, promoting distractor-resistance (Durstewitz, Seamans & Sejnowski, 2000), while high striatum DA (and relatively low PFC) promotes flexibility in updating relevant information (Frank, Loughry & O'Reilly, 2001).

Individual differences in DA concentrations within the PFC and striatum have been linked to individual differences in cognitive flexibility (Cools, 2008). It is thought that imbalance in control of various information processing systems involving DA plays a role in compulsive drug taking that characterizes addiction (Volkow, Wang, Fowler, Tomasi, Teland & Baler, 2010). Human brain imaging studies using positron emission tomography (PET), have shown that the DA increases induced by drugs are linked to the subjective experience of euphoria (or high) during intoxication (Volkow, et al., 1996, Volkow et al, 1999). Drugs of abuse can hijack or impair plasticity mechanisms related to reward processing in the brain (Kauer & Malenka, 2007; Dayan, 2009) resulting in powerful and long-lasting persistence of drug-seeking behavior. Although initial experimentation with a drug of abuse is largely a voluntary behavior, continued drug use can eventually impair neuronal circuits in the brain that are involved in goal-directed behavior, turning drug use into an automatic compulsive behavior. The ability of addictive drugs to co-opt neuro-transmitter signals between neurons (including dopamine, glutamate, and GABA) in affecting neuronal circuits changes over the course of an addiction trajectory (Kalivas & Volkow, 2005). Drug, drug cues or stress can drive unrestrained hyper-activation of the motivation/drive circuit that results in the compulsive drug intake that characterizes addiction.

Everyday life requires a continuous juggling act of multiple priorities that demand attention across various time scales. Given limited resources to attend to multiple priorities, over-attending to a given priority often comes at the expense of neglecting others. Compulsively engaging in a certain set of behaviors at the expense of other everyday responsibilities is one of the hallmark signs assessed in diagnostics for addiction (Grant, Brewer & Potenza, 2006). Behaviors that support the maintenance of addiction commonly do not support abstract goals (e.g. healthiness, happiness) or even concrete goals (e.g. abstinence; Everitt & Robbins, 2005).

1.3 Adapting to changes in environments or goals

One of the hallmark signs of addiction is the tendency to select addiction-related behaviors at the expense of behaviors that optimize health and wellness. A wide range of behaviors are susceptible to addictive tendencies and though many individuals engage in such behaviors, it is the loss of control in the engagement of these behaviors despite negative consequences that many addiction interventions seek to resolve. Maladaptive drug-seeking is commonly studied by exposing animals to drugs that are predicted by some kind of environmental regularity, then change the validity of this prediction, observe behavior, reinstate the validity, and observe behavior. Selective attention is highly sensitive to tangible changes in the current state of internal and external sensations and tends to bring these signals into our awareness, influencing subsequent actions. However, many changes occur on gradual time-scales and comprehension of this change may follow more of a step function (i.e. you don’t know until you know).

1.3.1 *Rejecting:* Extinction of cue responsivity following change

An important component of adaptive behavior is the ability to update responses in the face of changed contexts or contingencies. If a cue or conditioned stimulus (CS) that once predicted stimulus availability continues to appear when the previously associated stimulus is no longer available, the cue-driven conditioned responses (CR) tend to diminish over time. An extensive body of literature is dedicated to characterizing extinction-related behaviors and neural substrates across multiple species (Bouton, Westbrook, Corcoran, Maren, 2006). Though some early models of extinction learning proposed *erasure* of learning of the CS-US associative memory (Razran, 1956), several experimental observations indicate that extinction is not synonymous with "unlearning." For example, changes in context following extinction can lead to *renewal* of responding (Bouton & Bolles, 1979), the presentation of the unconditioned stimulus (US) alone can lead to *reinstatement* of responding (Rescorla & Heth, 1975) and if CS-US associations resume, animals exhibit rapid reacquisition of CRs (Napier, Macrae, & Kehoe, 1991).

While extinction has been a major topic of psychological research for the last century, more recently the potential clinical significance of extinction for the reduction of maladaptive behaviors has spurred research aimed at informing intervention techniques. It is thought that models of extinction have translational relevance for the protracted influence that addiction can have over behavior and the principles of extinction serve as the basis for some addiction intervention techniques (e.g. exposure therapy). Failure to extinguish CRs for drug-associated cues is commonly observed in animal models. Animals will persistently expend energy (lever press/nose poke/etc.) when a previous drug-paired cue (light/tone/smell/etc.) is presented, even if drugs are no longer administered. The behavioral vigor and duration depend on the schedule of cue presentation and reinforcement, but can also spontaneously recover (Rescorla, 2004). Similarly, in humans with a history of drug addiction, the exposure to drug-associated stimuli can trigger craving, drug seeking and ultimately use, despite an extended period of abstinence (Dimeff & Marlatt, 1998).

1.3.2 *Correcting?* Behavioral interventions and propensity for relapse

If, and when, individuals enter treatment for addiction, severe consequences related to health, family, community engagement and/or work productivity have likely already occurred (CDC, 2018). Though addiction is a major focus of science, medicine and social services, existing prevention and treatment techniques have poor long-term success rates. With high relapse rates in those attempting to remain abstinent and substance abuse-related deaths on the rise, as well as national economic costs estimated at over $700 billion annually (NIDA, 2017), it is imperative that more effective prevention, intervention and treatment techniques be developed.

While the studies of extinction and reinstatement discussed in the previous section have led to major advances in our understanding of learning and behavior, there is a lack of evidence that therapeutic interventions based on their principles are effective outside of laboratory settings (Conklin & Tiffany, 2002). In fact, a randomized controlled clinical trial of abstinent heroin-dependent inpatients found that, patients who received Cue-Exposure Therapy (CET) were *more likely* to dropout and relapse than a placebo group (Marissen, et al., 2007). Despite mixed evidence across research and clinical settings, techniques related to CET, such as attentional bias modification, are still commonly tested in the scientific literature (Zhang, Ying, Amron, Mahreen, Song, Fung & Smith, 2019) and are commercially available for self-enrollment.

According to the CDC (2018), current addiction therapies favor techniques like trigger identification and avoidance (Cognitive-Behavioral Therapy; McHugh, Hearon & Otto, 2010), stress-coping training (Mindfulness-Oriented Recovery Enhancement; Garland, Froeliger & Howard, 2014), and non-medical social-community support systems such as AA and NA. Over the last decade these techniques have started to incorporate computerized treatment delivery methods with some success, which may advance the ability to reach individuals in remote settings. For example, a study that compared the addition of biweekly computer-based CBT to a standard drug counseling treatment found that those who received the computer-based treatment had significantly higher numbers of drug free urine tests and longer periods of abstinence with benefits continuing through a 6 month follow-up (Carroll, Ball, Martino, Nich, Babuscio & Rounsaville, 2009). More recently, it has been proposed that "Prehabilitation" could serve as an intermediate step, prior to detoxification (Kouimtsidis, Duka, Palmer, Lingford-Hughes, 2019). Prehabilitation programs involve the initiation of partial control over substance use, the introduction of lifestyle changes for the individual in the environment they are currently using substances in, and addressing the role of immediate family and social environments. Programs such as the Structured Preparation before Alcohol Detoxification (SPADe) are currently in feasibility testing stages (Kouimtisidis et al., 2019).

Unfortunately, the regulation of currently available prehabilitation and rehabilitation techniques has not kept pace with their development and monetization across the United States. There appear to be major disconnects in some areas between scientific evidence-based intervention techniques that are published in the academic literature and the resources that are accessible to the public. For example, a recent review compared "attention bias" related training games or mobile applications that were evaluated scientifically and appeared in the published literature to the apps that were currently available for download on the Apple iTunes and Google Play app stores (Zhang et al, 2018). Of eight apps that were identified in the published literature, only one was commercially available. Conversely, of the 17 commercial apps that were identified, only one had been evaluated in the published literature. Even when intervention techniques seem promising in research studies and early trial stages, dissemination to those in need should be preceded by thorough assessments of their impacts and potential harms (e.g. CET-related relapse).

1.3.3 *Expecting:* The stable predictive validity of real world cues

It is extremely challenging to develop laboratory models that adequately capture the addictive behaviors of free-living human beings (Hyman, Malenka & Nestler, 2006). Limitations to extinction models of intervention techniques for addiction have been previously noted (Tobena, 1993), but these limitations mostly focus on the context specificity of extinction. It is well documented that re-exposure to substance-associated contexts can promote substance seeking, even after extinction of substance seeking in a different context (Janak & Chaudhri, 2010). Similarly, after seemingly successful stints in rehabilitation programs, environments that are saturated with familiar substance-related cues and contexts commonly lead individuals to revert to substance-seeking habits (Dunsmoor, Niv, Daw & Phelps, 2015) and precipitate relapse.

Extinction models are well suited for testing the predictors of *relapse* (Bouton & Swartzentruber, 1991; Bouton, Winterbauer & Todd, 2012), however their applicability for testing the predictors of *abstinence* is questionable. Laboratory models of extinction typically experimentally manipulate the availability of rewards in a given context or change the relationship between the rewards and the cues that they were previously associated with. Individuals addicted to substances of abuse have often learned, over months or years, to associate the reward of the drug with a unique set of stimuli and contexts. These stimuli and contexts are not arbitrary; they tend to be highly reliable and valid sources of information about the availability of particular substances. For example, neon “BAR OPEN” signs tend to indicate that entering the sign-bearing establishment and making a payment will lead to the procurement of alcohol. Furthermore, even if the relationship between a given cue and substances of abuse are no longer valid, in most cases these substances are still otherwise available.

Whereas an animal in a conditioning chamber cannot exit their confinement to seek substances that they are addicted to; if a human addict is exposed to an environment that attempts to regulate the availability of an addictive substance (e.g. rehab), this scenario is temporary. Once they exit this environment, they are faced with rampant availability and cues that resume their predictive relationships. Unless the availability of lethal addictive substances (e.g. fentanyl) are somehow eradicated from all non-medical settings and the production of substances with insidious long-term health ramifications (e.g. cigarettes) is stopped altogether, our intervention techniques need to take into consideration that these substances of abuse tend to always be accessible.

1.4 Overview of the current studies

This dissertation examines the reliability and validity of selective attention paradigms that have been adapted to study biased attentional priorities in humans, investigates the translational relevance of a task designed to measure incentive salience attribution in animals, and describes a novel method for measuring biased priorities in the management of multiple goals. We first tested the reliability and validity of the value-driven attentional capture (VDAC) paradigm. We found insufficient evidence to support the use of this measurement tool for characterizing individual differences in the construct it purports to measure. We then assessed the translational relevance of a Pavlovian conditioning task commonly used to train animals to associate rewards with cues. Using eye-tracking metrics, we found that the majority of participants dwelled on and vigorously interacted with reward-predictive cues, indicating cues acquired incentive salience. Finally, we developed a novel paradigm to assess behavioral tendencies to pursue reward opportunities, despite the accumulation of negative consequences. Overall, we observed persistent attempts to pursue rewards, even when this came at the expense of progress toward the overarching goals of the task. We tested two feedback manipulations and found that task performance was modulated by negative consequence-related feedback. Taken together, this work has implications for the development of prevention and intervention tools for maladaptive behavioral patterns that lead to the accumulation of negative consequences over time, such as addiction.

Chapter 2

On the *lack* of test-retest reliability of value-driven attentional capture

Attention bias is thought to be a key characteristic of a number of pathologies, including addiction (Field & Cox, 2008), anxiety (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg & van Ijzendoorn, 2007) and depression (Gotlib, Krasnoperova, Yue & Joormann, 2004). In the case of addiction, substance-related stimuli gain attentional priority and can promote craving and drug-seeking behaviors even after extended periods of abstinence. Unfortunately, behavioral interventions for maladaptive attentional biases, such as attentional bias modification, have been met with limited success (Emmelkamp, 2012, Mogg et al., 2017). The interventions that do show change in bias magnitude in laboratory settings often fail to generalize to changes in cravings or behavior following exposure to cues (Christiansen, Shoenmakers & Field, 2015). A better understanding of individual differences in attention bias is of critical importance for the development of more successful treatment techniques for various disorders.

While the extant literature on the clinical relevance of attention bias is relatively recent, basic selective attention research has been highly active over the last century (Driver, 2001). This literature focuses on understanding the prioritization of stimuli in the environment, given that typical environments include far more information than we can process at once. This prioritization may be influenced by current goals (top-down) and/or the physical salience (bottom-up) of stimuli in the present environment (Conner, Egeth &

Yantis, 2004). It has been proposed that bottom-up, top-down and experience-based priorities are integrated into “priority maps” that help guide selective attention (Awh et al., 2012). Attentional biases that develop for substance-related cues are experience-dependent biases, given that they may occur when the stimulus is not physically salient (does not stand out in its environment based on factors like color, shape, size, etc.) and/or is not related to currently active goals (e.g. abstinence).

Attempts to measure addiction-related attentional biases in laboratory settings have largely focused on the immediate, short-term, implicit effects of substance-related stimuli on selective attention. The paradigms utilized often focus on sub-second biases in task performance, either facilitating responses when a target replaces a relevant cue in spatial location (Dot-probe task; Ehrman et al., 2002) or delaying responses during conflict resolution (Stroop task; Cox, Farardi & Pothos, 2006) or search for task-relevant stimuli (Visual search; Oliver & Drobes, 2012). Popular paradigms have also been adapted for the measurement of reward-based attentional priority in healthy, non-addicted individuals. For example, a phenomenon known as value-driven attentional capture (VDAC) is characterized by the rapid orienting of attention toward cues previously associated with reward, even when the cue-reward association is no longer valid or task-relevant (Anderson, Laurent & Yantis, 2011). The standard visual search paradigm used to measure VDAC includes a reward-cue association phase, where colored stimuli are repeatedly paired with monetary rewards, followed by a distraction testing phase, where the previously rewarded stimulus is present, but task-irrelevant and no longer rewarded. Participants are typically slower to respond to the task-relevant targets when a previous reward cue is present compared to when no distractor cue is present. This pattern is taken to reflect an involuntary mechanism of attentional selection that is uniquely value-driven (Anderson et al., 2012) and is thought to reflect the same cognitive processes as addiction-related attentional biases (Anderson, 2016).

The apparent translational relevance of VDAC has prompted the use of this paradigm in studies of addiction (Anderson, Faulkner, Rilee, Yantis, & Marvel, 2013), depressive symptoms (Anderson, Leal, Hall, Yassa, & Yantis, 2014; Anderson, Chiu, DiBartolo & Leal, 2017), adolescent development (Roper, Vecera & Vaidya, 2014), HIV (Anderson, Kronemer, Rilee, Sacktor, & Marvel, 2015), stroke patients with hemifield neglect (Bourgeois, Saj & Vuilleumier, 2018), ADHD (Sali, Anderson, Yantis, Mostofsky & Rosch, 2018) and Autistic traits (Anderson & Kim, 2019). While VDAC study results are typically reported at the group level, substantial individual differences in the magnitude of distraction have been observed and the variability in capture has been compared to clinically relevant individual differences. VDAC magnitude has been found to be positively correlated with impulsivity (Anderson, Kronemer, Rilee, Sacktor, & Marvel, 2015) and dopamine receptor availability in the dorsal striatum (Anderson, Kuwabara, Wong, Gean, Rahmim, et al., 2016) and negatively correlated with depressive symptoms (Anderson, Leal, Hall, Yassa, & Yantis, 2014) and sometimes working memory capacity (Anderson, Laurent & Yantis, 2011, but see Anderson, Faulkner, Rilee, Yantis, & Marvel, 2013). For some individuals, the previous value-associated distractors greatly impair task performance while for others no measurable impairment is observed (Anderson et al., 2017). However, while the group level-attention bias appears to be robust and replicable across studies, the reliability and validity of individual differences measures of VDAC magnitude are not well understood.

The factors underlying the large variance in VDAC remain unclear and yet are of critical concern given the adoption of VDAC visual-search paradigms for the purpose of characterizing individual differences and possibly determining treatment regimens in addicts and other clinical populations. There has been limited examination of reliability of individual difference in VDAC magnitude to date. Before VDAC can be applied in settings either as a diagnostic tool or measurement of intervention (such as attentional bias modification) effectiveness, it must be established whether or not VDAC magnitude is stable and trait-like in nature and if it is reliable across and within test sessions.

Three studies have examined the replicability of VDAC in the same group of individuals at two time points. Two of these studies measured group-level capture at two separate times points and the third measured individual-level capture at two separate time points. First, Anderson & Yantis (2013) tested college-aged young adults on the typical VDAC visual search training phase- test phase paradigm across several studies. Seven to nine months later, some of these prior participants from different studies were then recruited to complete a second session that only included the test phase. During the second session, the presence of previous high-value distractors slowed RT relative to the distractor present and low value distractor conditions. The authors concluded that VDAC persists for long periods of time without continued reinforcement.

Second, HIV+ individuals were presented with the typical VDAC visual search training and testing phases during an initial laboratory session. Participants returned to the lab 6 months later and completed a second testing phase (Anderson, Kronemer, Rilee, Sacktor, & Marvel, 2015). During the first session, test-phase response times were significantly longer on trials that included high-value distractors vs. trials that did not.

However, unlike session one, during the second session participants were not slower to respond on trials when a high-value distractor was present relative to when it was not. While the authors did observe similar correlations between the magnitudes of capture and score on the Barrett Impulsivity Scale (BIS-11) across sessions, they did not report a correlation for VDAC scores on session 1 vs. 2.

A third study sought to directly establish the test-retest reliability of VDAC in a version of the paradigm adapted for measuring gaze contingent responses (Anderson & Kim, 2018). In this study, participants completed both the training phase and test phases on two separate days. During the test phase, in addition to the typical response time (RT) measures, the percentage of initial fixations on distractors were measured in each distractor condition. On distractor-absent trials, in order to quantify the probability of initially fixating a distractor for the sake of comparison, the authors randomly selected another non-target shape on each trial. Like the previous studies, the authors observed the typical group-level VDAC pattern in reaction time on day one, however they did not report group-level VDAC results for day two. When they compared the magnitude of capture (High-Value RT – Distractor Absent RT) in the first session to the second, they did not observe a correlation. It is not the case that capture scores were simply diminished or that the lack of correlation is attributable to a restricted range of scores on the second session. In fact, a substantial portion of the participants *increased* in capture magnitude from session 1 to session 2 and there was an even greater range of capture scores in session 2 (approximately -40 ms to 70 ms) compared to session 1 (approximately -25 ms to 55 ms). There was one factor that was reported as being consistent across days— the percentage of initial fixations in the region of the previously high value distractor.

Despite all previous studies concerned with individual differences in VDAC primarily focusing on reaction time, the fixation pattern was taken as evidence that VDAC is consistent and reliable at the individual level, reflective of a trait-like characteristic, and therefore appropriate for use in clinically relevant domains.

In general, measurements such as reaction time are highly consistent in individuals across different tasks and task conditions. However, a critical aspect of capture estimation is the baseline correction achieved by the subtraction of distractor-absent from distractor-present conditions. Baseline RT varies between subjects, but RT tends to be highly intercorrelated across conditions and test sessions (Hedge, Powell & Sumner, 2018). Only correlating the percentage of initial fixations on high-value distractors is akin to only correlating high-value distractor RTs across time points, and as just described, RT measures tend to be highly reliable across sessions. Therefore, the reliability of capture has yet to be confirmed. To examine the stability and reliability of VDAC magnitude, we tested participants on two versions of the VDAC task on two separate days. In addition to replicating the lack of test-retest reliability of RT measures from Anderson & Kim (2018), we sought to establish the reliability of these scores within an individual session. If magnitude of attention bias, as measured by slowing of reaction time in the face of previous reward cues, is trait-like in nature, then individual attention bias scores should be correlated within and across test sessions.

2.1 Experiment 1

Methods

Participants

Thirty participants were recruited to take part in Experiment 1. Twenty-five participants completed both testing sessions and were included in the subsequent analyses. The sample included 8 males and had an average age of 20 years (3.64 SD). All participants had self-reported normal or corrected-to-normal visual acuity and normal color vision. Each participant completed two 2-hour session separated by 1-3 days. Sessions took place at the same time of day and participants were asked to try to equate the amount of sleep obtained, food and caffeine consumed prior to each testing session.

Design

During each experimental session, participants completed two variants of the VDAC paradigm. All aspects of the variants were identical other than the feedback provided following correct responses during the training phase and corresponding payment structure. In one variant, correct responses were rewarded with the addition of monetary bonuses to the total earnings for participating in the experiment. In the other variant, participants were provided with a "bank" of $20 dollars at the beginning of the task. Correct responses resulted in the avoidance of the loss of money from the starting bank (Figure 1). The motivation for correctly responding in the task differed across the task variants, therefore we refer to the variants as "motivational contexts." The order of the motivational contexts was counterbalanced across participants and flipped across sessions for each participant. Each motivational context resulted in the accumulation (reward variant) or savings (loss-avoidance variant) of approximately $15 per session.

Procedures

Training phase. The training search array consisted of a white fixation cross surrounded by six colored circles (2.3° diameter) placed at equal intervals on an imaginary circle with a radius of 5°. The screen background was black. The targets were defined as two pre-specified colored circles, one of which was presented on each trial. Participants were randomly assigned a color pair (red-green or blue-yellow) for each feedback task-variant. Within a motivational context, one of the two colors in a given pair was followed by high-value feedback (15¢) on 80% of the trials and low-value feedback (3¢) on 20% of the trials. For the other color the value-color probabilities were reversed. Color-value-feedback mappings were the same across the two testing sessions.

Inside the target circle, a white line was oriented either vertically or horizontally. The color of the other five circles was drawn randomly from the set (purple, cyan, pink, orange, brown, white) on each trial, without replacement. Inside each of the non-targets, a white line was tilted at 45° to the left or to the right (randomly determined for each non-target). Participants were instructed to respond with a left button press for a vertical line

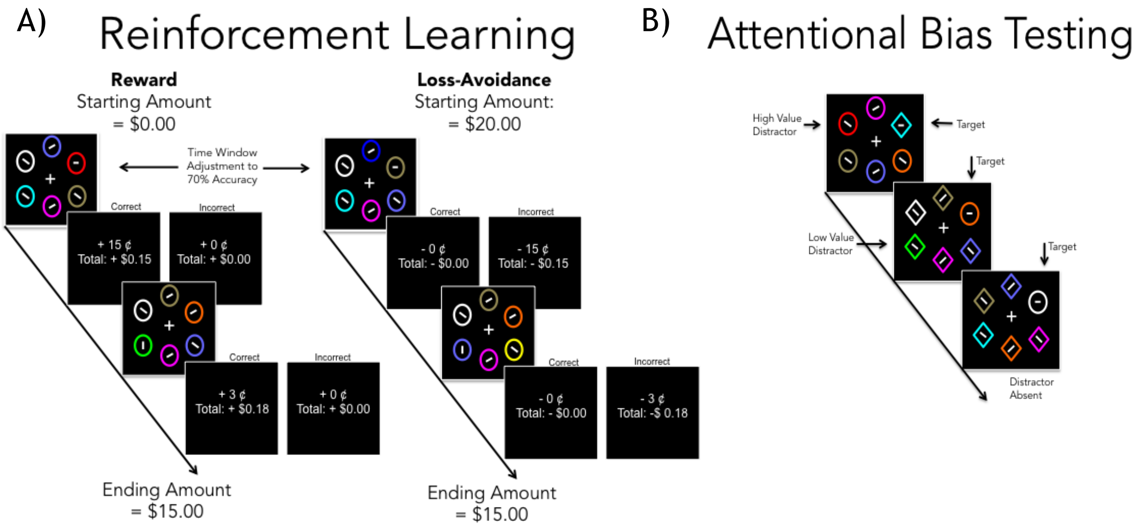

Figure 1. Experiment 1 task paradigm. A) VDAC training phase task variants. B) Test phase task-paradigm.

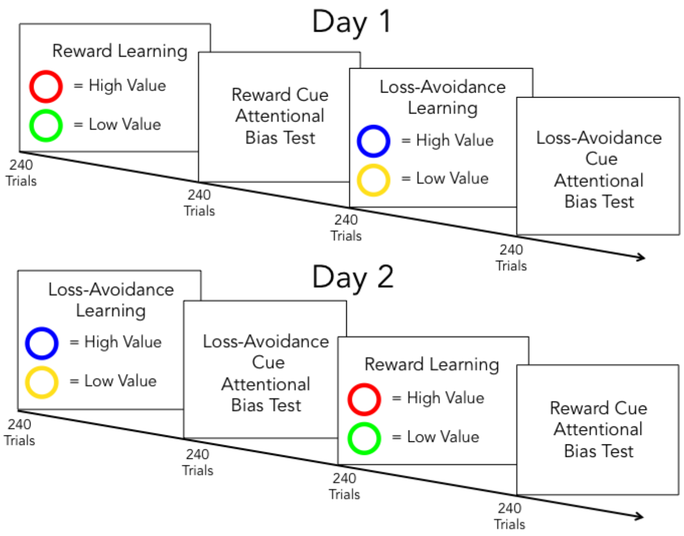

Figure 2. Experiment 1 task procedures during each session. Color-value-feedback mappings were held constant across sessions, but the order in which the motivational contexts were completed was reversed.

or a right button press for a horizontal line with the "z" and "m" keys on a standard keyboard, respectively. The two target colors and all target locations were fully crossed and counterbalanced, and trial types were presented in a quasi-random order. If participants did not respond before the search array disappeared, the computer emitted a 500-ms 1000-Hz tone indicating that the trial had timed out. In both motivational contexts, the display presentation time was manipulated based on participant performance to maintain an average of about 70% correct. This manipulation was implemented to ensure that participants had adequate exposure to the color-value associations within the loss-avoidance task, but did not experience a level of negative feedback that would lead to perceived ineffectiveness of effort to perform well. Fifty practice trials were included at the beginning of the session. Following practice, 240 training trials were completed with one break halfway through (minimum of 30 seconds, self-terminated by button press).

Test phase. Each trial began with the presentation of a fixation cross for an interval of 400, 500, or 600 ms, selected quasi-randomly. The search display then appeared and remained on screen until a response was made or the response window timed out after 1200 ms. Each display consisted of six colored shapes with the same arrangement as described in the training phase, with the exception that one of the shapes was different from the rest (either a circle among diamonds or a diamond among circles). Participants were instructed to indicate the orientation (horizontal or vertical) of the line inside the unique shape. They were informed that color was irrelevant to the task and should be ignored. On 50% of the trials, a target color from the training phase was included as a distractor among the non-target shapes (25% previous target color 1, 25% previous target color 2). The display was followed by a 1000-ms error feedback display if the participant had responded incorrectly or failed to respond before the deadline, and then a 500-ms ITI. Twenty practice trials (previous target colors absent) on the shape task were included prior to the 240 test trials. One break was provided halfway through (minimum of 30 seconds, self-terminated by button press). Following completion of the first motivational context, participants were provided with a break and then completed the second motivational context.

Results

Group-Level: We carried out a 2x2x3 mixed-design ANOVA on the test-phase capture scores, with the factors test session (day 1, day 2), motivational context (reward, loss-avoidance) and distractor-value (absent, low, high). We observed a significant main effect of day, $F(1,25) = 64.36$, $p < .001$, $\eta p^2 = .720$, a significant main effect of distractor value $F(2,50) = 8.56$, $p = .001$, $\eta p^2 = .255$ and no effect of motivational context $F(1,25) =$

0.85, $p < .366$, $\eta p^2 = .033$ or any interactions between factors (all Fs < 1, ps > .35). Means and standard deviations for each condition are reported in Table 1.

Table 1. Descriptive Statistics and Test-Retest Reliability for Experiment 1.

	Reward		Loss		
	Day 1 *M (SD)*	Day 2 *M (SD)*	Day 1 *M (SD)*	Day 2 *M (SD)*	*r*
Absent RT	623 (69)	563 (68)	633 (95)	567 (69)	**.729*****
Low-Value RT	629 (74)	571 (75)	645 (100)	572 (73)	**.731*****
High-Value RT	634 (75)	571 (72)	643 (100)	577 (63)	**.686*****
High-Value Capture	11 (24)	08 (22)	11 (20)	10 (20)	.094

Note: Values rounded to the nearest integer. Acronyms: RT: Response Time. Capture is calculated by subtracting the Absent RT from the High-Value RT. Test-Retest reliability accessed across feedback groups. ***p < .001

Bonferroni post-hoc comparisons were conducted to test for differences across the various conditions. As expected, RT significantly decreased from day 1 to day 2, $p < .001$. Comparisons of RT across distractor value-conditions indicated that both high-value-distractor RT ($p = .002$) and low-value distractor RT ($p = .016$) were significantly slower than distractor present RT. High-value and low-value distractor RT conditions did not significantly differ.

Within each day and context we performed paired samples t-tests to test for RT differences between value conditions (Table 2).

Table 2: Distractor Condition RT Comparisons

Reward		Day 1		Day 2	
RT 1	RT2	*t*	*p*	*t*	*p*
Absent	Low-Value	1.62	.118	2.00	.056
Low-Value	High-Value	0.87	.391	0.01	.993
Absent	High-Value	2.27	.032*	1.80	.083

Loss-Avoidance		Day 1		Day 2	
RT 1	RT2	*t*	*p*	*t*	*p*
Absent	Low-Value	2.83	.009**	2.52	.018*
Low-Value	High-Value	0.30	.770	1.08	.289
Absent	High-Value	2.74	.011*	1.07	.297

**p < .01, *p < .05

Individual-Level: Next, we compared individual differences in VDAC magnitude across test session days. We calculated VDAC for each day in each motivational context by subtracting the average RT on high-value distractor-present trials from the average RT on distractor absent trials and tested for correlations across and within test sessions

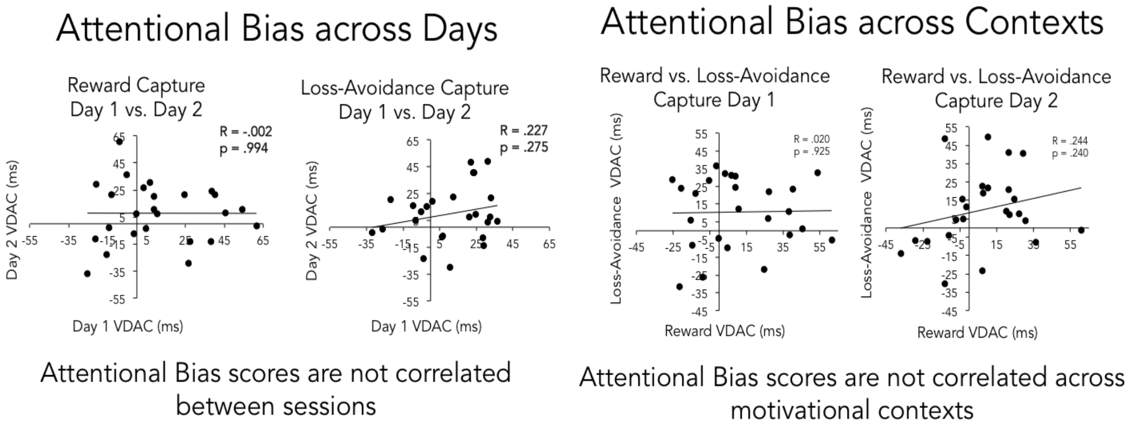

Figure 3. VDAC Magnitude Results. VDAC (High Value RT- Absent RT) is not correlated across days or motivational contexts (reward vs. loss-avoidance).

(Figure 3). Neither reward-based (r = -.002, p = .994) or loss avoidance-based (r = .227, p = .275) VDAC scores were correlated across test sessions. Within a given session, VDAC scores were not correlated across motivational contexts (day 1: r = .020, p = .925; day 2: r = .244, p = .240).

Caveat: Order Effects Thus far, the results of Experiment 1 demonstrate that, though VDAC is evident at the group-level across days and motivational contexts, the magnitude of the effect for a given individual is not consistent across days or contexts. However, in the previous analysis, we did not examine the role of the *order* of motivational context that participants were assigned on capture magnitude. It's possible that the first day motivational-context-order or the switching of motivational-contexts-orders across days could play a role in the magnitude of capture or lack of correlation between the test sessions. Unfortunately, further breaking down participant groups by task-variant order limits our ability to test for correlations within a given day/context/order group, so we tested for group level effects in motivational context order.

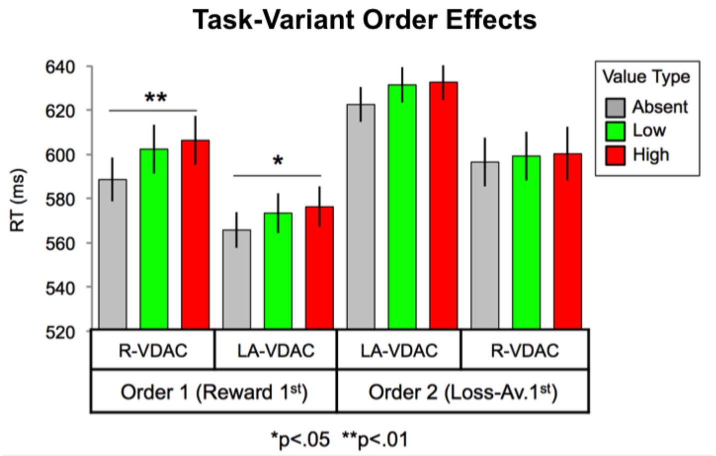

Figure 4. VDAC order effects. VDAC depended on the order in which the task-variants were completed. The group that received reward feedback first showed significant group-level capture in both variants. The group that received loss-avoidance feedback first did not show significant group-level capture in either variant. Error bars reflect ±1 SEM.

Results

We carried out a 2x2x3 mixed-design ANOVA on the day 1 test-phase capture scores, with the factors motivational context (reward, loss-avoidance), context order (reward 1st, loss-avoidance 1st) and distractor-value (absent, low, high). We observed a significant main effect of distractor value, $F(2,46) = 7.82$, $p = .001$, $\eta p^2 = .254$ and a significant interaction between motivational context and context order, $F(1,23) = 33.05$, $p < .001$, $\eta p^2 = .590$. All other main effects and interactions were not significant ($Fs < 2.1$, $ps > .05$). We evaluated the VDAC effect in each context and order and found that the group that received the reward context first showed VDAC in both reward and loss-avoidance contexts, however the group that received the loss-avoidance context first did not significantly differ in RT for any of the distractor-value conditions across both contexts (See Figure 4).

Discussion

We tested the group- and individual-level reliability of VDAC across two sessions in two motivational contexts. We found that VDAC was consistent at the group-level across days and contexts, however individual differences were not reliable across days or contexts. When we examined the role of task-variant order on group-level VDAC, we found that this factor influenced the magnitude and significance of the effect across contexts. It's possible that the participants that were assigned to one variant-order condition were more susceptible to VDAC and therefore exhibited greater distractor costs, however it is also possible that the order in which participants performed the task under different motivational contexts influenced the capture magnitude and lack of correlation across days. In Experiment 2, we tested individuals on only one of the two motivational contexts across days, eliminating potential context order effects. We also tested the consistency of components of the VDAC score (individual condition RTs) and variety of self-report measures across days.

2.2 Experiment 2

Methods

Participants

Participants were recruited from the Johns Hopkins University Community. A total of 48 participants completed variants of the VDAC training-phase/test-phase paradigm on two separate days. On each day, half of the participants (N = 24) received reward-based feedback and the other received loss-based feedback during the VDAC training phase. Age, gender and demographic information are summarized in Table 1.

Procedures

All aspects of the design and procedures were identical to Experiment 1, with the following exceptions. Participants were randomly assigned to one of the two feedback task-variants (reward or loss-avoidance) and color-value pairs (red-green or blue-yellow) were randomly assigned to day 1 or day 2.

Questionnaires

Participants completed a battery of self-report questionnaires at the beginning of each testing session. This battery included the Behavioral Inhibition System/ Behavioral Activation System Scales (BIS/BAS; Carver et al., 1994), the Barrett Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995), the Beck Depression Inventory-II (BDI-II; Beck, Steer & Brown, 1996), the Barkley Adult ADHD Rating Scale IV (BAARS-IV; Barkley, 2011) and the Autism Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). The BIS/BAS assesses dispositional sensitivities to reward and punishment anticipation. The BIS-11 assesses the personality construct of impulsiveness through items related to behaviors and preferences. The BDI-II is a measure of severity of depressive symptoms within a two-week timeframe prior to the time of assessment. The BAARS-IV measures inattention and hyperactivity-impulsivity factors associated with attention deficit/hyperactivity disorder (ADHD). The AQ measures the degree to which typically functioning adults have traits associated with the autism spectrum disorder (ASD). Questionnaires were completed on a computer using Qualtrics, an online survey tool. At the end of the study, participants completed a follow-up survey regarding their experiences and strategies implemented in the task.

Results & Discussion

We carried out a 3x2x2 mixed-design ANOVA on the test-phase capture scores, with the factors distractor-value (absent, low, high), task-variant (reward, loss-avoidance) and test session (day 1, day 2). We observed a significant main effect of distractor value, F(2,92) = 11.51 p < .001, $\eta p^2 = .200$, significant main effect of day F(1,46) = 71.10, p < .001, $\eta p^2 = .607$ and a significant interaction between distractor value and test session, F(2,92) = 8.98, p < .001. Means and standard deviation for each day and context are reported in Table 1. Post-hoc comparisons revealed that the difference in high-value and distractor absent RT was significant in both motivational contexts on day 1, on day 2 no VDAC effects were observed at the group level.

Table 3: Descriptive Statistics and Test-Retest Reliability for Experiment 2.

	Reward		Loss		
	Day 1 *M (SD)*	Day 2 *M (SD)*	Day 1 *M (SD)*	Day 2 *M (SD)*	*r*
N	24		24		
Gender (% Female)	71		79		
Age	23 (04)		21 (03)		
BDI Depression	08 (07)	07 (09)	07 (06)	05 (05)	**.937*****
Autism Quotient	18 (08)	18 (09)	16 (06)	16 (07)	**.910*****
BIS-11 Impulsivity	59 (11)	58 (10)	59 (11)	58 (11)	**.915*****
Barkley ADHD	18 (08)	18 (09)	16 (06)	16 (07)	**.887*****
BIS Inhibition	20 (05)	20 (04)	21 (03)	21 (03)	**.871*****
BAS Approach	38 (05)	39 (05)	39 (04)	39 (05)	**.889*****
Absent RT	656 (81)	599 (75)	659 (55)	597 (62)	**.686*****
Low-Value RT	661 (88)	604 (73)	666 (61)	601 (60)	**.690*****
High-Value RT	675 (91)	603 (72)	681 (69)	595 (63)	**.656*****
High-Value Capture	19 (31)	05 (17)	22 (29)	-01 (19)	-.068

Note: Values rounded to the nearest integer. Acronyms: BDI: Beck Depression Inventory; BIS-11: Barrett Impulsivity Scale, version 11; BIS: Behavioral Inhibition System; BAS: Behavioral Activation System; RT: Response Time. Capture is calculated by subtracting the Absent RT from the High-Value RT. Test-Retest reliability accessed across feedback groups. ***p < .001

At the individual level, we observed strong correlations between all factors tested on day 1 and day 2 (self-report questionnaire scores and individual condition RTs; all r values > .600, all p values < .001), with the exception of the VDAC score (High-Value RT – Distractor-Absent RT; r = -.068, p > .05, See Figure 5). Means (*M*), standard deviations (*SD*) and *r*-values for each day and context are reported in Table 1.

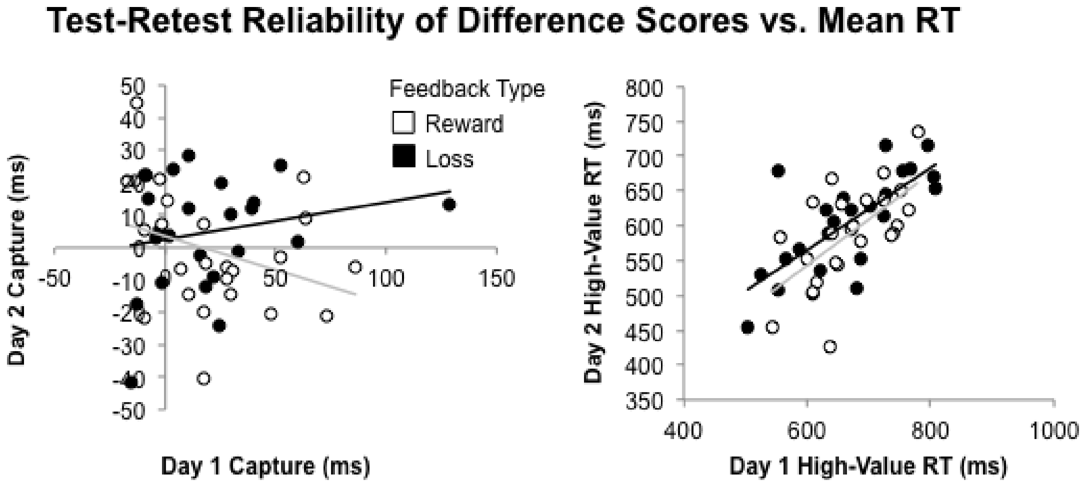

Figure 5. Test-Retest Reliability of Difference Scores and Mean High-Value RT. A) Capture scores (High Value RT – Distractor Absent RT) are not correlated between sessions in either reward or loss avoidance contexts. B) Mean High-Value RT is highly correlated between sessions in both reward and loss avoidance contexts.

Discussion

In Experiment 2, we found that the standard VDAC paradigm does not produce consistent group-level capture or correlated individual differences in capture. In contrast, the other measures that we tested for consistency across test sessions (including RT on individual distractor conditions and a battery of self-report questionnaires) were all highly correlated. On day one, we replicated the basic VDAC effect in both reward and loss-avoidance contexts: slowing of responses in the presence of a task-irrelevant, but previously reward-associated stimulus. However, on day 2 we did not observe significant RT effects in either condition.

The factors underlying the lack of day 2 capture observed in Experiment 2 and the source of variability in capture magnitude driving the lack of correlation across days remain unclear. Our findings are consistent with the lack of day 2 capture reported in a prior 2-day test of VDAC (Anderson, Kronemer, Rilee, Sacktor, & Marvel, 2015) and the lack of correlation in RT measures of VDAC across testing sessions (Anderson & Kim, 2018). Should the large variance in VDAC magnitude and poor test-retest reliability simply be attributed to noise in the RT measures? Or are there other fixed factors in the design that have yet to be accounted for?

Though we eliminated the potential order effects that influenced capture in Experiment 1, our design in Experiment 2 included another fixed factor that differed between the two days— the colors of the high-value reward- or loss- associated stimuli. Even though the color-pairs and sessions were counterbalanced across participants, it's possible that the difference in color-value pairs across testing sessions underlies the between session differences. Unfortunately, once all factors that were counterbalanced are separated in the current design, size of the cells of each condition are in limited in size and therefore suitability for testing the role of each individual factor. Chapter 3 examines the role of color in driving capture in the VDAC paradigm.

Conclusions

It has been claimed is a VDAC robust measure of the lingering effects of reward on attentional priority at the individual level and therefore is a candidate for the assessment of the effectiveness of intervention techniques (e.g. Attentional Bias

Modification (ABM)). Experiments 1 and 2 present evidence that attention capture, as measured by the VDAC paradigm, is not a reliable measure of individual differences within or across days or motivational contexts. Evidence from the current study supports previous findings that RT based measurements of capture are not reliable across sessions and furthermore, suggest that capture is unreliable *within* a given session across contexts. Though it has been claimed that eye-tracking metrics provide measure of VDAC that is reliable across test sessions, the evidence supporting this claim did not sufficiently account for baseline differences across individuals and therefore should be interpreted with caution. The current study found highly reliable individual differences within a single trial type (e.g. high-value distractor present) but not for capture scores, where RT for the distractor present condition is compared to the baseline distractor absent condition.

Chapter 3

Color Drives Capture in the Value-Driven Attentional Capture Paradigm

Though the lack of reliability observed in Chapter 2 suggests that the VDAC measure is not well suited for the assessment of intervention techniques, the group-level effect has been replicated repeatedly across multiple laboratories. Experiments 3-9 challenge the claim that capture, as measured by the VDAC paradigm, is independent of the physical characteristics of the distractors. Instead, we observed evidence that the magnitude of capture depends on the presence of *red* distractor stimuli as well as several other issues that limit the validity of the measure overall.

The processes that guide selective attention are heavily debated. Whereas classic attentional control frameworks emphasize the dichotomy between top-down (voluntary, goal-driven) and bottom-up (automatic, stimulus-driven) selection, it has recently been proposed that lingering attention biases that arise from selectively attending to stimuli in the past represent a third category: *selection history* (Awh, Belopolsky, & Theeuwes, 2012; Theeuwes, 2018). Value-driven attentional capture (VDAC)— the rapid orienting of attention toward stimuli previously associated with reward, regardless of current goal-relevance or physical characteristics of the stimuli (Anderson, Laurent & Yantis, 2011) is considered to be evidence for the distinctiveness of selection history from other drivers of attention is. As described in Chapter 2, studies of VDAC typically utilize a two-part visual search paradigm where red and green targets are first paired with relatively high or low value (e.g. money) during a training phase and subsequently appear as distractors in a test phase where color is task-irrelevant. In the test phase, average response time (RT) is longer when the high-value distractor color is present vs. absent from the search array. Average RT when the low-value distractor color is present is often numerically in-between the average RTs for the high-value distractor present and distractor absent conditions (though not always statistically significantly different from either one). This combination of results has been interpreted as evidence that relatively high-value stimulus features capture attention even when they no longer signify reward availability.

VDAC has been observed following association of red and green targets with monetary reward (e.g. Anderson et al., 2011), images of money, images of monopoly money (Roper & Vecera, 2016), game feedback (Miranda & Palmer, 2014) and emotive faces (Anderson, 2016; Anderson & Kim, 2018). The average magnitude of the capture effect observed in the test phase is relatively small but surprisingly similar across different types of incentives—typically on the order of 10 – 20 ms. Interestingly, capture magnitude is also similar across a wide range of "high-value" reward amounts ($0.05 – $1.50; Anderson et al., 2011; Anderson et al., 2016), amount of training during color-reward pairing (144 – 1008 trials; Sali, Anderson & Yantis, 2014; Anderson et al., 2011), time between training and testing (a few minutes – 9 months; Anderson & Yantis, 2013), and even, in some cases, basic selection history in the absence of value-related feedback (e.g. Sha & Jiang, 2016; Grubb & Li, 2018). While the specifics of the training phase typically do not influence capture magnitude, one factor has remained largely consistent across the aforementioned studies: the colors. During training, participants search an array for red or green targets that are paired with variable levels of reward. One of these color-defined targets (counterbalanced across participants) has an 80% probability of high-value feedback (e.g. 5¢) and 20% probability low-value feedback (e.g. 1¢) following correct responses; for the other target color, this mapping is reversed. Participants are not explicitly informed of the relationship between color and reward magnitude, but it is assumed that they learn it over the course of training. Counterbalancing and control experiments have been used to provide evidence against the possibility that color could play a role in driving the capture effect, but the evidence ruling out this factor is limited.

The initial report of VDAC (Anderson et al., 2011) tested for distractor-color based effects in a control study that omitted the training phase and only included the test phase. No significant difference in RT was observed as a function of distractor condition (red, green, or absent). However, that control study included eight participants (compared to 26 in the primary experiment). As a result, there was questionable statistical power to detect a potential effect of distractor-color, raising doubt whether that null difference is meaningful. Another study measuring the persistence of VDAC tested for an interaction between distractor color and the effects of distractors on performance, but again the power to detect this effect was questionable with thirteen participants included and unequal color-value groups (8 red, 5 green; Anderson & Yantis, 2012). Other researchers using the VDAC paradigm also observed no significant differences in RT for the red distractor, green distractor or distractor absent conditions in several control experiments in which participants performed only the test phase, but their analyses were also likely underpowered with 7–9 participants included per control experiment (e.g., Miranda & Palmer, 2014; Jiao, Du, He & Zhang, 2015). Unlike these test-phase-only experiments, the role of color has not been assessed in the selection history variants of the paradigm that omit reward feedback during the red- and green-target selection training phase. These experiments generally test for differences in distractor-present vs. distractor-absent RTs, collapsing across colors rather than comparing the distractor-absent condition to the red-distractor and green-distractor conditions separately (Anderson et al., 2011; Sha & Jiang, 2016; Anderson & Halpern, 2017; Grubb & Li, 2018).

Considering the fact that red and green were counterbalanced across the high- and low-value conditions in previous studies, it may seem unlikely that color played a role in VDAC. However, it should be noted that several studies have found no difference between high- and low-value distractor RTs (Anderson et al. 2011; Anderson & Yantis, 2012; Anderson, Laurent & Yantis, 2014; Miranda & Palmer, 2014; Sha & Jiang, 2016; van Koningsbruggen, Ficarella, Battelli & Hickey, 2016). Furthermore, it has been acknowledged that the magnitude of capture at the individual level is highly variable across subjects, at times rendering the group-level RT effects non-significant (e.g. Anderson et al., 2017). Given the inconsistencies in VDAC results across the literature, further examination of the fixed factors that differ between subjects (i.e. color-value assignments) is warranted. If a portion of the variance in VDAC is attributable to color, differences in the number of participants assigned to each color-value mapping group (due to exclusion, attrition, or odd numbers of subjects) could underlie differences in observations across studies.

In the present set of experiments, we tested the claim that VDAC, as measured by the VDAC paradigm, is independent of the color of the distractor stimuli. We first present a replication of the standard VDAC paradigm (Experiment 1). When we analyzed the data with the conventional methods (repeated-measures ANOVA on value condition RT) we replicated the seminal VDAC results: a main effect of value and significantly longer high-value distractor RT than distractor-absent RT. However, when we included color in the analysis, we observed a main effect of color that did not interact with value, and no effect of value. We then present experiments that tested the necessity of selection history (Experiment 2) or task history (Experiment 3) in driving the capture effects observed in this paradigm, followed by a test of alternative target/distractor colors (blue and yellow; Experiment 4). Finally, we present three replications demonstrating the role of color in driving capture magnitude (Experiments 5–7). The results of the following experiments consistently demonstrate that red stimuli drive attentional capture effects in the VDAC paradigm, regardless of value-association or selection history.

General Methods

Participants

Participants were recruited from the Johns Hopkins University community and participated to earn extra course credit (Experiments 3-8) or earn monetary compensation (Experiment 9). Of the experiments that recruited participants for extra course credit, Experiments 3, 4, 6 and 8 additionally compensated participants with monetary bonuses determined by their task performance (Anderson, Chiu, DiBartolo & Leal, 2017). Participants gave written informed consent prior to the experiment and the Institutional Review Board of the Johns Hopkins University approved the study.

Inclusion Criteria. All participants had self-reported normal or corrected-to-normal visual acuity and normal color vision. Previous VDAC studies have varied in the practice of excluding participants based on test-phase accuracy. Most commonly no accuracy criterion is reported, but in some studies participants have been excluded based on performance at chance levels (Anderson et al., 2016), three standard deviations below the average group accuracy (Miranda & Palmer, 2014), <60% accuracy (Anderson & Kim, 2018), <70% accuracy (Anderson, 2016) and <75% accuracy (Sali et al., 2014). Given this variability in criteria, we analyzed our data sets with each of the previously used accuracy cutoffs and observed that changing the inclusion threshold did not impact the conclusions of our analyses (Supplemental Figure 2). Therefore, we included all participants tested.

Materials and Procedure

Training phase. Replicating methods from previously published VDAC studies, Experiments 3-4 and 6-9 included a visual search "training phase" with the following design features. In each of these experiments, the search array consisted of a white fixation cross surrounded by six colored circles (2.3° diameter) placed at equal intervals on an imaginary circle with a radius of 5°. The screen background was black. The targets were defined as two pre-specified colored circles, one of which was presented on each trial (colors described in individual experiment methods sections below). Inside the target circle, a white line was oriented either vertically or horizontally. The color of the other five circles was drawn randomly from the set (blue, cyan, magenta, orange, yellow, white) on each trial, without replacement. Inside each of the non-targets, a white line was tilted at 45° to the left or to the right (randomly determined for each non-target). Participants were instructed to respond with a left button press for a vertical line or a right button press for a horizontal line. The two target colors and all target locations were fully crossed and counterbalanced, and trial types were presented in a quasi-random order. If participants did not respond before the search array disappeared (800 ms), the computer emitted a 500-ms 1000-Hz tone indicating that the trial had timed out. Feedback following correct responses within the time window varied across experiments and is described for each experiment below. Fifty practice trials were included at the beginning of the session. Following practice, 240 training trials were completed with one break halfway through (minimum of 30 seconds, self-terminated by button press).

Test phase. All experiments included a test-phase visual search task. Each trial began with the presentation of a fixation cross for an interval of 400, 500, or 600 ms, selected quasi-randomly. The search display then appeared and remained on screen until a response was made or the response window timed out after 1200 ms (Anderson & Halpern, 2017). Each display consisted of six colored shapes with the same arrangement as described in the training phase, with the exception that one of the shapes was different from the rest (either a circle among diamonds or a diamond among circles). Participants were instructed to indicate the orientation (horizontal or vertical) of the line inside the unique shape. They were informed that color was irrelevant to the task and should be ignored. On 50% of the trials, a target color from the training phase was included as a distractor among the non-target shapes (25% previous target color 1, 25% previous target color 2). The display was followed by a 1000-ms error feedback display if the participant had responded incorrectly or failed to respond before the deadline, and then a 500-ms ITI. Twenty practice trials (previous target colors absent) on the shape task were included prior to the 240 test trials. One break was provided halfway through (minimum of 30 seconds, self-terminated by button press).

Analysis. Incorrect responses and correct responses faster than 200 ms and slower than 3 SD from the mean RT were excluded from all analyses of RT (means and SD calculated and corresponding exclusions made per subject, per condition). We chose this type of outlier thresholding for consistency with the commonly reported practices in the analysis of data from this paradigm, but like the accuracy cutoffs previously mentioned, there is also variability of trial-level outlier thresholding in this literature. In addition to the <200 ms and >3 SD technique, other studies report a >2.5 SD cutoff (Anderson, 2015; Anderson, 2017), a <150 ms cutoff (Roper et al., 2014) or do not report a cutoff criterion (Jiao et al., 2015). As described in Miller (1991), using SD cutoffs to restrict the means of positively skewed RT distributions introduces a bias of underestimating the true average of the response times and, importantly, this bias depends on the number of samples in the distribution. Because there are double the number of distractor-absent trials than those in either distractor-present condition, there is likely to be a better estimation of the sample average and standard deviation in the former, and therefore some samples from the long right tail of the distractor-absent distribution will meet exclusion criteria. However, in the distributions with fewer samples (each distractor-present condition) long RTs tend to inflate both the sample average and SD, making it less likely that those data points will be excluded by thresholding. In our current data sets we examined the effects of different trial-level SD cutoffs (examples presented in Supplemental Figure 3). The use of standard deviation cutoffs *did* inflate VDAC capture magnitude across experiments. In the current experiments, our conclusions about the sources of the VDAC effect held regardless of the particular thresholding used. However, given the inflated magnitudes of the VDAC effect we observed, trial-level exclusion criteria may be an important factor that should be evaluated for existing VDAC data sets and considered in future analysis-pipeline decisions.

Questionnaires. Before performing the visual search tasks, participants completed a battery of self-report questionnaires. Immediately after the test phase, participants completed a follow-up questionnaire about their experiences performing the tasks. The questionnaire data were collected to examine individual differences in capture magnitude and is not relevant to the current manuscript; those results will be reported in detail elsewhere.

Equipment. A Mac Mini equipped with MATLAB and Psychophysics Toolbox (Brainard, 1997) was used to present the stimuli on an Asus VE247 monitor. The

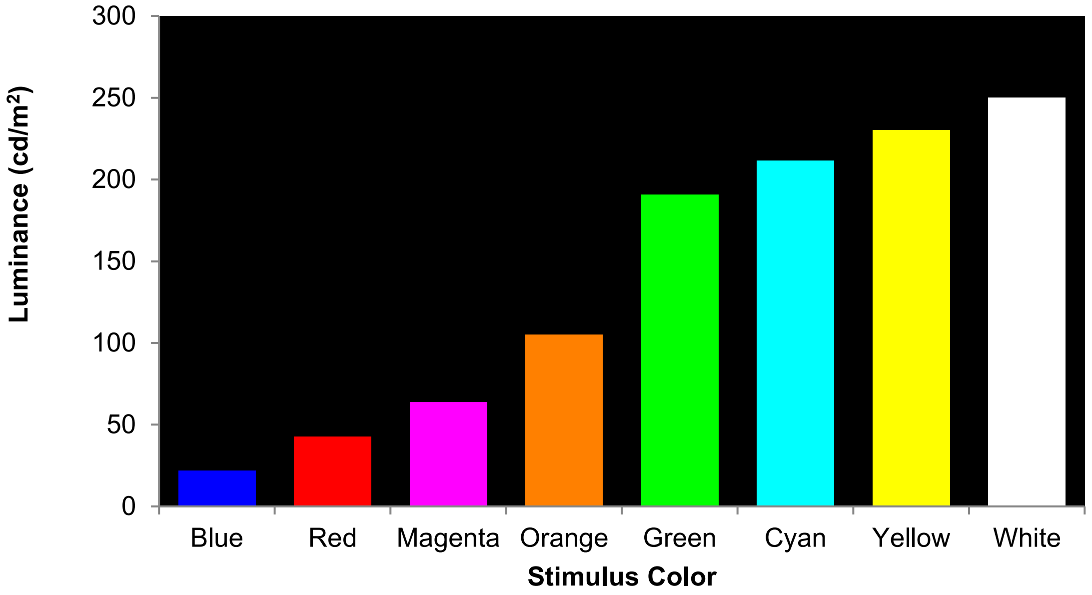

Figure 6. Luminance (cd/m^2) for each stimulus color in the visual search display. Given that the differences in luminance between blue and yellow did not lead to differences in capture effects (Experiment 4), it's unlikely that the luminance differences between red and green (red stimuli having lower luminance than green stimuli) caused the increased attention capture by red stimuli observed.

participants viewed the monitor from a distance of approximately 50 cm in a dimly lit room. Manual responses were made with the left and right index fingers on the “z” and “m” keys, respectively, using a Mac keyboard. We used a photometer (LiteMate/SpotMate Photometer System, Photo Research, Kollmorgen Corp., 1983) to verify that luminance differences between the distractors could not explain the observed results in our experiments (Figure 7).

3.1 Experiment 3: Does Color Influence Capture Magnitude in the VDAC Paradigm?

Despite mixed results across the literature, some studies have shown statistically longer RT for high-value than low-value distractors (e.g. Anderson & Halpern, 2017). These results do seem to support the existence of attention capture that is dependent on value and not color; however, value-color interactions are not typically reported. To test the role of color in driving capture magnitude in the VDAC paradigm, we conducted a VDAC replication experiment. We first analyzed the test phase RT data in the conventional way (repeated-measures ANOVA on distractor-value conditions) and then with a mixed-design ANOVA that included distractor color in addition to color-value mapping condition. In the standard VDAC test phase, all participants are presented with distractor-absent trials, red-distractor trials, and green-distractor trials; therefore we included color as a within-subjects factor in our analysis. The intention of the training phase in the VDAC paradigm is to imbue red with high value and green with low value for half of the participants and the opposite color-value mapping for the other half of participants, and therefore we included color-value mapping as a between-subjects factor. If value drives capture regardless of distractor color, then an interaction should be observed between the distractor color and color-value mapping group— RTs should be greater for red in the red-high value group and green in the green-high value group. However, if instead color drives capture, a main effect of color that does not interact with the intended color-value mapping should be observed.

Method

Participants

Consistent with previous VDAC studies (e.g. Anderson & Halpern 2017), we recruited 40 participants including 11 males and 29 females with an average age of 19.1 (1.2 SD) years.

Procedures

Participants completed a visual search task (training phase) for a red or green target circle, reporting the orientation of a line inside of it (Fig. 1A), followed by monetary-reward feedback: half of the participants had an 80% probability of receiving high-value feedback (5¢) and 20% probability of receiving low-value feedback (1¢) following correct responses for red targets, and 80% probability of receiving low-value feedback and 20% probability of receiving high-value feedback following correct responses for green targets. For the other half of participants, the color-value probability mappings were reversed. In the subsequent test phase, participants completed a unique-shape search task in which the color of the shapes was task-irrelevant (Fig. 1B). On half of the trials, a previous target color was included as a distractor among the non-target shapes (25% red distractor, 25% green distractor). The remaining half of trials did not include the colors red or green and were considered "distractor-absent."

Results and Discussion

First, we employed the conventional VDAC analysis: a repeated measures ANOVA with distractor condition (absent, low-value, high-value) as a within-subjects factor. We replicated the pattern reported in the initial VDAC paper (Anderson et al, 2011): a main effect of distractor value, F(2,78) = 4.5, p = .014, Bonferroni-corrected post hoc comparisons (Anderson & Kim, 2019) indicated that RTs were significantly longer in the high-value-distractor condition than in the distractor-absent condition, p = .034, and the low-value-distractor condition did not significantly differ from the distractor-absent condition, p = .088, or the high-value distractor condition, p = .908 (See Figure 7A).

Next, we carried out a mixed-design ANOVA on test-phase RT, with distractor

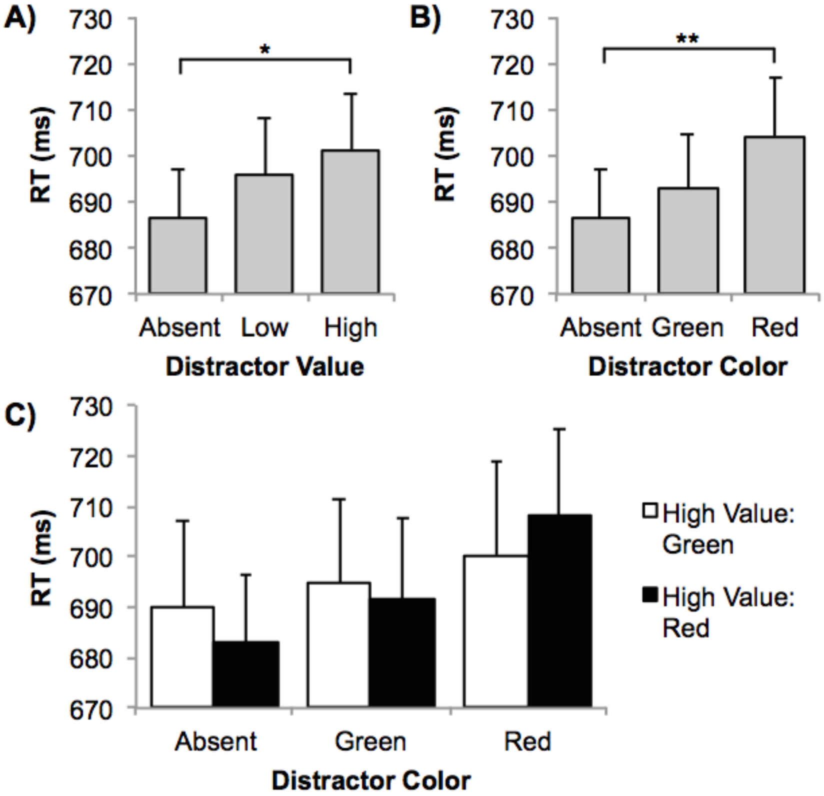

Figure 7. Test phase response time (RT) results from Experiment 3. A) RT by distractor value condition. B) RT by distractor color condition C) RT by distractor color condition for each color-value group. Error bars reflect +1 SEM. **p < .01, *p <.05.

color (absent, green, red) as a within-subject factor and value-color group (red-high vs. green-high) as a between-subjects factor. We observed a main effect of distractor color, F(2,76) = 6.79, p = .002. However, there was no effect of value-color group F(1,38) = .001, p = .970, and, critically, no interaction between value-color group and distractor color, F(2,76) = 1.26, p = .29 (Figure 7C).

Table 4. Test Phase Reaction Time Results for Experiments 3–9

		Absent		Green		Red						
Exp.	Group	*M*	*95% CI*	*M*	*95% CI*	*M*	*95% CI*	*Test*	*F*	*df*	*p*	ηp^2
3	Red-High	683	652-714	692	658-725	708	672-744	**Color** Col*Val Value	**6.79** 1.26 .001	**2,76** 2,76 1,38	**.002** .289 .970	**.220** .048 .000
	Green-High	690	659-721	695	661-728	700	664-737					
4	RGRG	647	627-667	648	626-670	663	641-686	**Color** Col*Hist History	**8.53** 2.05 .146	**2,160** 2,160 2,80	**<.001** .132 .704	**.157** .027 .002
	BYRG	643	622-664	647	625-670	650	627-673					
5	Response deadline	723	704-742	724	703-744	718	699-737	Color	.828	2,78	.441	.021
	No deadline	904	847-961	900	839-961	908	848-968	Color	.480	2,78	.621	.012
7	SH	648	626-669	648	625-671	659	636-682	**Color**	**4.90**	**2,58**	**.011**	**.145**
8	Red High	646	616-676	634	605-662	667	636-697	**Color** Col*Val Value	**33.0** .290 .260	**2,68** 2,68 1,33	**<.001** .595 .769	**.497** .009 .008
	Green High	656	625-687	642	613-671	681	650-712					
9	Red High	638	602-673	637	601-674	653	615-691	**Color** Col*Val Value	**5.80** .209 .005	**2,76** 2,76 1,38	**.005** .812 .945	**.132** .005 .000
	Green High	641	605-676	641	604-678	652	614-689					
		Absent		Blue		Yellow						
6	BYBY	675	652-698	676	654-699	678	654-702	Color	.379	2,78	.686	.010

Note: Bold text indicates statistical significance. Acronyms & Abbreviations: Col: Color; Val: Value; Hist: History; RGRG: Red-Green Training, Red-Green Testing; BYRG: Blue-Yellow Training, Red-Green Testing; SH: Selection History Training; BYBY: Blue-Yellow Training, Blue-Yellow Testing.

Bonferroni-corrected post hoc comparisons indicated that RTs were significantly longer in the red-distractor condition than in the distractor-absent condition, p = .007, and that the green-distractor condition did not differ from the distractor-absent condition, p = .383, or red-distractor condition, p = .085 (Figure 7B).

In summary, our results indicate that RT is slowed in the presence of red, but not green, distractors regardless of prior reward association. When the data were analyzed in the conventional method, we replicated the typical value-driven effect. However, analyses that included distractor color in addition to "value" revealed a main effect of color that did not interact with value, and no effect of value. The omission of color from the standard analysis obscures the importance of this factor in driving capture magnitude and if we had, like previous studies, limited our analysis to only include the value factor, we might have concluded that value drove the observed pattern of results.

3.2 Experiment 4: Does the Red Distractor Effect Depend on Selection History?

There has been some debate over the value-dependence of the results from the VDAC paradigm, but this has mainly centered on the limited ability to rule out the role of selection history in driving the observed effects (Sha & Jiang, 2016; Anderson & Halpern, 2017; Grubb & Li, 2018). Like typical VDAC experiments, these selection history experiments required participants to repeatedly select red and green stimuli during a training phase, but then the colors are collapsed in analyzing the distraction effects. In Experiment 4, we tested for a replication of the red distractor effect observed in Experiment 3 in two variants of the training-phase/test-phase paradigm in order to evaluate the dependence of this effect on selection history. Two groups of subjects performed training-phase/test-phase versions of the VDAC paradigm, with one critical between-group difference: during the training phase, one group of subjects selected red and green targets, and another group selected blue and yellow targets. To ensure both equivalent reward- and selection history across all colors, each color was paired with a high-value reward on half of the training trials and a low-value reward on the remaining half. Following training, both groups of subjects performed identical test phases that included red distractors on 25% of the trials, green distractors on 25% of the trials and neither of these colors on the remaining 50% of the trials. If the slowing of RT in the presence of red distractors depends on selection history, then the magnitude of capture should be greater in the group of subjects that selected red and green during training, versus the group that selected blue and yellow during training.

Method

Participants

We recruited 82 participants to participate in Experiment 4. Of these participants, 42 selected red and green during training (Group RGRG) and 40 selected blue and yellow during training (Group BYRG). In Group RGRG, one participant failed to complete the testing phase and was replaced with an additional participant. The final RGRG sample included 11 males and 31 females with an average age of 19.8 (1.5 SD) years. Group BYRG included 9 males and 31 females, average age of 19.4 (1.2 SD) years.

Procedures

All procedures were identical to Experiment 3, with the exceptions that each color was paired with a high-value reward (5¢) on half of the training trials and a low-value reward (1¢) on the remaining half, and that group BYRG selected blue and yellow as targets during the training phase.

Results

We carried out a mixed-design ANOVA on the test-phase capture scores, with distractor condition (absent, green, red) as a within-subjects factor and selection history color group (RGRG vs. BYRG) as a between-subjects factor. There was a main effect of distractor color, F(2,160) = 8.53, p < .001 (See Table 2). Distractor color did not interact with selection history color group F(2,160) = 2.05, p = .13 and we observed no main effect for selection history color group, F(1,80) = 0.146, p = .70. Bonferroni-corrected

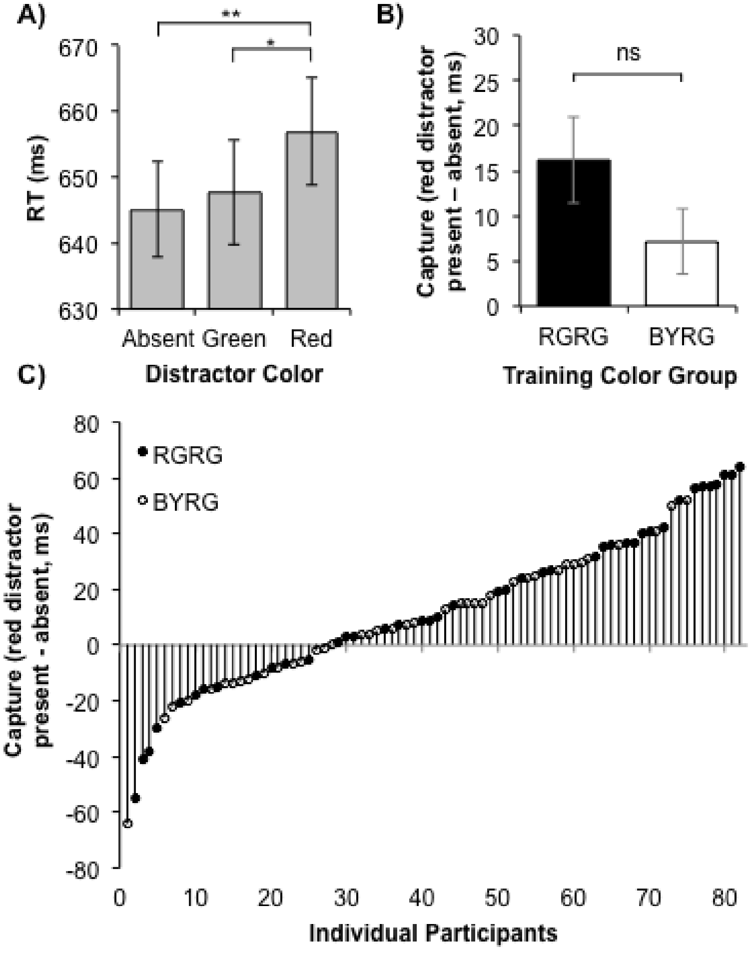

Figure 8. Test phase results from Experiment 4. A) RT by distractor color condition. B) Average red distractor capture by training color condition. C) Individual red distractor capture scores. Error bars reflect +1 SEM. **p < .01, *p <.05.

post hoc comparisons indicated that RTs were significantly longer in the red-distractor condition than in both the distractor-absent condition, p = .001 and the green-distractor condition, p = .017. The green-distractor condition did not significantly differ from the distractor-absent condition, p = .336 (See Figure 8A).

Next, we compared average red-distractor capture scores from the RGRG group to those from the BYRG group. Following standard procedures for measuring capture, we subtracted average distractor-absent RT from the average red-distractor RT for each participant. An independent-samples t-test indicated that red capture did not differ between the two training color groups t(80) = 1.49, p =.139 (equal variances not assumed). Group-level and individual-level red capture scores are presented in Figure 8B and 8C, respectively.

Discussion

In Experiment 4, we observed a red distractor effect that did not depend on selection history for red stimuli. Regardless of whether participants searched for red and green targets or blue and yellow targets in a context where they were equally likely to receive with high or low rewards following correct responses, subsequent presentation of red distractors produced significant attention capture.

3.3 Experiment 5: Does the Red Distractor Effect Depend on Task History?

The results of Experiments 3 and 4 indicate that attention capture observed in variants of the training-phase/test-phase VDAC paradigm depends on distractor color, but a question remains about the necessity of training-phase history to drive the red distractor effect in the test phase. As previously mentioned, studies that have attempted to rule out a difference between distractor absent, green distractors, and red distractors by omitting the training phase found no VDAC for either red or green stimuli, but those studies were either underpowered or collapsed across color conditions. Furthermore, an unaddressed issue in comparing RT data from versions of the paradigm that include a training phase vs. those that do not is the overall reduction in test-phase RT for participants who were provided with extensive practice on the line-orientation judgment during a training phase vs. those that were not. This may be important because, in a paradigm that enforces a 1200-ms response deadline, it's possible that slowing of visual search due to the presence of distractors may manifest in time-out errors, rather than in longer RT for correct responses made prior to the deadline on those trials. Experiment 5 tested for RT and accuracy (% correct) differences between the red, green, and distractor absent conditions in the VDAC paradigm test phase. If red capture is independent of task practice, the presence of red distractors should significantly increase RTs relative to trials where no distractor was present, even when the training phase was omitted. We also conducted a control study to assess the influence of the test-phase response deadline on capture magnitude.

Method

Participants & Procedures

We recruited 40 new participants in Experiment 5, including 14 males and 26 females with an average age of 19.4 (0.9 SD) years. We also recruited 40 participants to complete the control study that omitted the response deadline, including 12 males and 28 females with an average age of 19.1 (1.3 SD). All exclusion criteria, procedures, and analyses were identical to the previously described experiments, with the exception that participants completed only the test phase. As in Experiment 3, the target unique shapes were never red or green, and so red and green colored shapes are referred to again as "distractors."

Results

A repeated-measures ANOVA on Experiment 3 test-phase RT did not indicate a significant main effect of distractor condition, F(2,78) = 0.828, p = .441 (See Table 2). However, accuracy differed between the distractor conditions, F(2,78) = 4.91, p = .01. Bonferroni-corrected post hoc comparisons indicated that the red-distractor condition had significantly lower accuracy (M = 85%, SD = 7.7%) than the green-distractor condition (M = 88%, SD = 6.5%), p = .023. The distractor-absent condition (M = 87%, SD = 5.7%) did not significantly differ in accuracy from the green-distractor condition, p = .365 or the red-distractor condition, p = .246

We replicated the RT results of Experiment 5 in the control study; repeated-measures ANOVA on test-phase RT did not indicate a significant main effect of distractor condition, F(2,78) = 0.480, p = .621 (See Table 2). Without the response deadline, participants were highly accurate in their responses in the distractor absent condition (M = 96%, SD = 2.7%), green condition (M = 96%, SD = 3.4%) and red condition (M = 96%, SD = 3.6%) and these conditions did not significantly differ, F(2,78) = .03, p = .971.

Discussion

We replicated previous results (Anderson et al., 2011; Miranda & Palmer, 2014; Jiao, Du, He & Zhang, 2015) that RT does not significantly differ across conditions when the test phase is completed without a training phase. However, we also observed a significantly lower accuracy for the red- vs. green-distractor conditions. It is important to note that this accuracy difference complicates the interpretation of the RT data because this task enforces a response deadline. In addition to incorrect button presses, responses that failed to beat the deadline (potentially due to distractor capture) are scored as errors. This limitation may be especially important to consider in experiments that compare capture scores between groups of subjects that differ in baseline test-phase RT, such as those who did or did not perform a training phase.

3.4 Experiment 6: Do Other Colors Produce Capture in the VDAC paradigm?

In Experiment 5, we investigated whether colors other than red produce attention capture effects in the test phase following equivalent reward and selection history. Perhaps it is only green distractors that show reduced capture effects relative to red distractors. Though the overwhelming majority of studies use red and green, the colors blue and yellow have also been counterbalanced across value conditions in the VDAC literature (Anderson et al. 2017). When blue and yellow were used as high- or low-value distractors in addition to red and green (color pairs counterbalanced across participants) in that previous study, no significant main effect of distractor-value condition was reported (though it's possible that this null result was due to inadequate power, with N = 11). If capture magnitude depends on the presence of red distractors, then blue and yellow distractors should not slow RT relative to the distractor-absent condition, regardless of reward- and selection history.

Method

Participants & Procedures

We recruited 40 new participants in Experiment 6. The sample was composed of 13 males and 27 females with an average age of 19.6 (1 SD) years. All exclusion criteria, procedures and analyses were identical to the previous experiments, with the exception that rather than searching for red and green targets in the training phase, participants searched for and were equally rewarded for blue and yellow targets during the training phase, and were presented with blue and yellow distractors in the test phase.

Results & Discussion

A repeated-measures ANOVA on test-phase RT indicated there was not a significant main effect of distractor condition F(2,78) = 0.379, p = .686 (See Table 2). Similar to the pattern observed with green distractors in the previous experiments, history with equally rewarded blue and yellow targets was not sufficient to produce subsequent attention capture by blue or yellow distractors. These results are inconsistent with value-driven or selection-history-driven attention capture being independent of the physical characteristics of the distractors.

3.5 Experiments 7-9

After finding that capture magnitude is color-specific, we re-analyzed three data sets from the VDAC paradigm. These data sets were collected prior to those described thus far with the goal of examining individual differences in capture magnitude, but they were not previously assessed for color-related effects and have not been reported elsewhere.

Method

Participants & Procedures

A total of 105 participants took part in experiments 7-9 (30, 35, and 40, respectively). *Experiment 7* tested for selection history attention capture following training that omitted reward feedback. Participants trained on the line-orientation task with red or green circle-targets for 1000 trials, immediately followed by 288 test trials. *Experiment 8* was a VDAC paradigm replication. Participants were randomly assigned to a color condition; either red or green was associated with a high-value reward (5¢) on 80% of the trials and a low reward (1¢) on the other 20%. The reward probability was reversed for the other color. Experiment 9 was thus identical to Experiment 3 except that participants trained for 1000 instead of 240 trials, immediately followed by 288 test trials. In *Experiment 9*, rather than receiving positive reward feedback, participants attempted to avoid losing money from a starting amount ($20). Participants were randomly assigned to a color condition; either red or green was associated with a relatively high-value loss (15¢) and a low-value loss (3¢) for the other color, for 100% of incorrect responses. During training, the time window during which participants could respond was adjusted on a trial-by-trial basis to ensure 30% incorrect responses (averaged across values), therefore providing sufficient exposure to the loss feedback. Participants completed 362 training trials and 240 test trials.

Results

Of primary importance, in all of these three experiments, we observed significant capture for red, but not green, distractors (Figure 9). In each experiment, we observed a main effect of color, and in Experiments 8 and 9, where color-value-mappings were counterbalanced across participants, there was neither a main effect of value nor an interaction between color and value (Table 2).

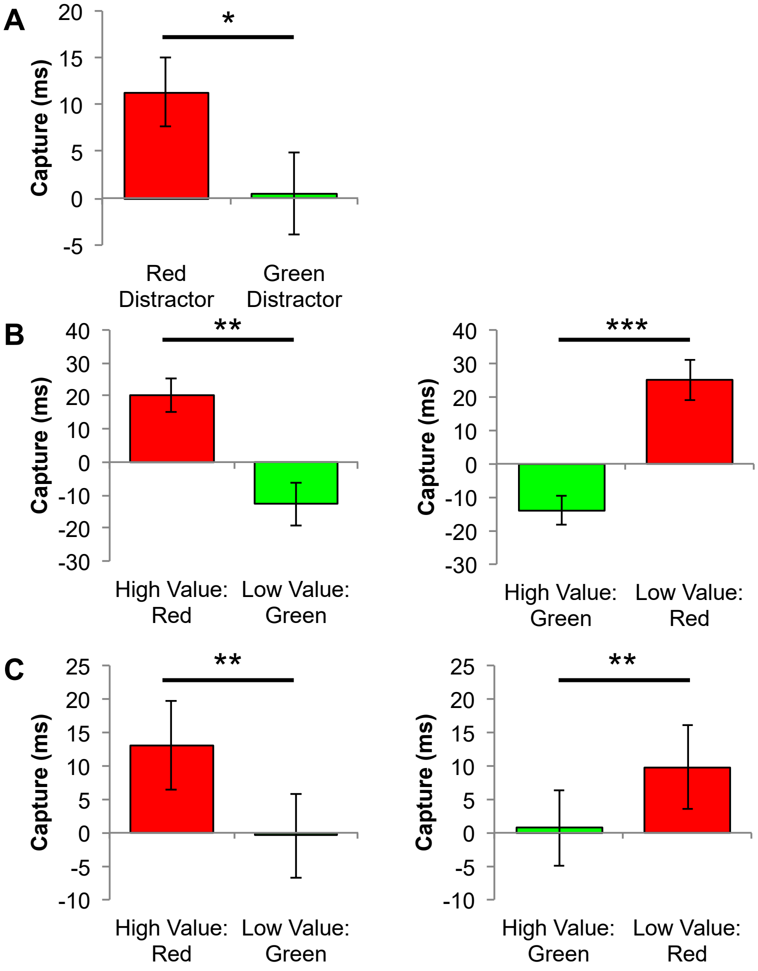

Figure 9. Test phase capture results for Experiments 7-9 (panels A, B, C, respectively). Capture magnitude = distractor-color RT minus distractor-absent RT. *p < .05, **p < .01, ***p < .001

Discussion

Across several data sets we replicated the color dependence of capture magnitude in the VDAC paradigm. Red distractors, but not green distractors, consistently produced longer RTs than when distractors were absent. This pattern did not depend on positive (reward) or negative (loss-avoidance) valence of incentives in the training phase (Exp. 8-9) or even the presence of value feedback in the training phase (Exp. 7).

Summary & Concluding Discussion

Contrary to previous claims that results from the VDAC paradigm are independent of the physical characteristics of distractors, the effects we observed depended on distractor color. Capture effects consistently depended on the presence of red distractors, regardless of training type (selection history, equal color-reward associations, unequal color-reward associations, or unequal color-loss associations). When the training phase was omitted, no significant RT effects were observed. However, when a response deadline was enforced, a color-based effect was observed in accuracy, with red distractors producing worse performance relative to green distractors. Our results suggest that practice with the visual-search and line-orientation judgment task may be needed to reduce overall RTs enough to reveal attention bias to red distractors. Rather than performing control studies to assess potential effects of color, the full data sets used as evidence for value-dependent capture should instead be directly tested for color-based effects.

The assignment of particular colors to experimental conditions is an extremely common practice in laboratory studies of selective attention. In a summary of color-specific effects in attention allocation, Folk (2015) noted that it is surprising that color-condition interactions are rarely observed in selective attention research. He highlighted prior evidence that color influences non-selective components of attention (arousal and vigilance), other aspects of cognition, and even target detection in visual search (referencing work by Mikellides, 1990; Wilson, 1966; Elliot & Maier, 2014; and Lindsey, Brown, Reijnen, Rich, Kuzmove, & Wolfe, 2010). This evidence, as well as a large body of color psychology research, suggests there is a unique influence of the color red. In fact, there is evidence that trichromacy evolved in humans and some other primates to confer survival benefits from the discrimination of red stimuli encountered in foraging (detecting ripe berries and fruit) and mate selection (flushing, indices of healthy oxygenation levels; Gerl & Morris, 2008). Use of the color red to capture attention is common in modern designs— some of the most popular brand logos designed to grab our attention incorporate the color red (e.g. Coca-Cola, Marlboro, McDonalds, Budweiser). Additionally, compelling support for the special significance of red in visual processing has recently been observed at the level of electrophysiological signals recorded from primate area V1. Long wavelength (reddish) hues induced stronger gamma oscillations relative to other hues or achromatic gratings (Shirhatti & Raya, 2018). While our results are specific to the VDAC paradigm, color-dependent effects or interactions could potentially affect hundreds of studies across the selective attention literature that use red and green stimuli within or across conditions.

Our results raise a considerable red flag for the design of the VDAC paradigm. However, we also acknowledge that the variants of VDAC paradigm that we employed in this set of studies do not cover the full range of variants that have been employed across the literature. It is possible that previous studies that have utilized alternative value-training procedures produced color-independent results. In fact, a different training-phase-test-phase paradigm has recently shown that the strength of the reward learning during training is strongly related to the magnitude of attentional capture during testing (Jahfari & Theeuwes, 2017).

One of the motivations behind the development of the VDAC experimental paradigm was to provide a controlled method of inducing and measuring attention biases in the laboratory that were independent of long-term reward learning history. Attention bias is thought to be a key characteristic of drug addiction (Field & Cox, 2008), but one of the difficulties of studying attention bias in individuals addicted to substances of abuse is that each person has learned, over months or years, to associate the reward of the drug with a unique set of stimuli and contexts. It was thought that in the same way a syringe can capture attention and elicit cravings in an abstinent individual with a history of heroin addiction, the VDAC paradigm showed that colored shapes that were previously paired with monetary rewards could capture attention as well. However, there is a lack of evidence that participants explicitly learn to associate target colors with variable levels of reward during the training phase. Individuals with addiction history are acutely aware of the relationship between syringes, drugs, and their effects. In contrast, across this literature it has been reported that the short-term implicit association between colors and monetary value in the VDAC paradigm, does not drive explicit learning for the majority of participants. For instance, a study that measured VDAC in individuals with a history of addiction and controls reported that approximately 80% of participants did not demonstrate explicit awareness of the relationship between color and value during training (Anderson, Faulkner, Rilee, Yantis, & Marvel, 2013).

Finally, we caution that there are other problems with the interpretation of data from this paradigm. First, highly reliable sources of variance in the current data sets have nothing to do with the intended value or color conditions, but instead reflect other stimulus features (e.g., responses to test-phase circle targets are on average ~100 ms faster than to diamond targets) and response biases (Simon effects and switch costs). Any slight difference in proportion of these effects in one condition vs. another due to participant-specific errors could feasibly drive a small (e.g. 10 ms) RT difference, which

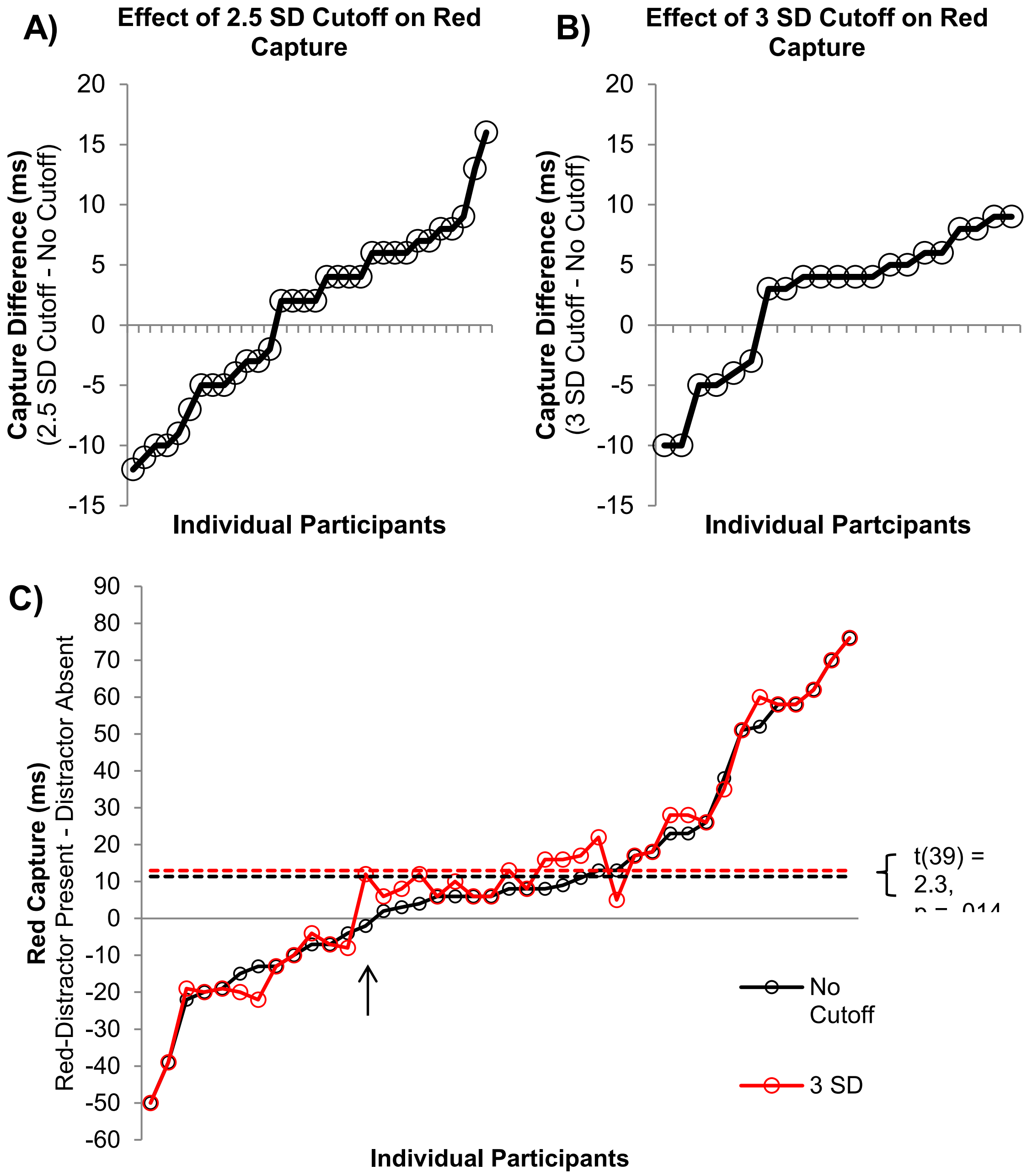

Figure 10. RT Trimming Effects. A) The effect that cutting off data 2.5 SD above the mean for each condition has on the magnitude of red capture in Experiment 3. B) The effect that cutting off data 3 SD above the mean for each condition has on the magnitude of red capture in Experiment 1. C) Experiment 9 data are presented here to highlight the influence that cutoffs can significantly inflate average capture magnitude. The arrow highlights a case where an individual went from negative capture (-2 ms) to above average capture (13 ms) based solely on the 3 SD cutoff.

is on the order of the typical VDAC effect. Second, the use of strategies to minimize effort during the search tasks is commonly acknowledged by participants, including ignoring everything in the display other than the vertical or horizontal line (the only information actually needed to make a response). A strategy like this could lead to the maximization of rewards earned in the training phase, but also minimize the associative learning between the colors of the stimuli and the relative monetary values. And, lastly, using analyses that assume Gaussian distributions of the RTs (which they are not) and equivalent distractor-condition distribution estimations (which they do not have) can lead to subtle problems in the treatment of data, particularly when it comes to outlier trimming. The trial-level RT outlier trimming procedures described earlier in the general methods section may not seem like a large problem, given that the RT trimming typically leads to exclusion of <2% of trials (Anderson & Halpern, 2017). However, one of the reasons that the RT trimming procedure affects so few trials is that the standard deviations are so large that the 3 SD cutoffs are greater than the response deadline for many individuals. In our replication study (Experiment 3), 42.5% of participants had 3 SD cutoffs for at least one condition that exceeded the response deadline. For those participants that are subjected to RT trimming, capture magnitude is influenced by this arbitrary thresholding. Throwing out just one data point from one condition is enough to cause a >10 ms shift in an individual's capture magnitude (Figure 10). Thus, it is important with VDAC and similar research paradigms that potential sources of variance, such as stimulus features, and the potential impact of choices in the analysis pipeline be carefully considered without over-dependence on under-powered control studies or analysis procedures accepted as "standard" but potentially misleading, according to our findings.

Conclusions

We found that the magnitude of attention capture was driven by the red distractor stimuli regardless of prior reward association or selection history. Though analyses of color-based effects are not commonly reported in the VDAC literature, here we show it is an important factor to consider in the interpretation of results from this paradigm. Do people pay attention to rewarding stimuli? Yes, but in the case of this paradigm there is limited evidence that individuals associate reward with the colors. Unfortunately, simply changing the colors of the stimuli will not solve the validity problems with the VDAC paradigm, but hopefully bringing these issues to light will aid in the development of measurement tools in this important line of research.

Chapter 4

Incentive salience attribution predicts task-irrelevant attention biases in human sign- and goal-trackers

Despite findings that VDAC (DiBartolo, Gmeindl & Courtney, submitted) and other attentional bias paradigms (Christianson, Schoenmakers & Field, 2015) may not be valid measurements of *value*-based attentional priorities, it is generally accepted that attention guides information selection to maximize rewards (Gottlieb et al. 2014). Reward-based learning can alter attentional priority maps even after brief instances of pairing (Chelazzi et al., 2014). However, as described in Chapter 3, there is limited evidence that participants explicitly learned the associations between colors and relatively high- or low- monetary values during the VDAC training task. In addition to the previously described studies, a recent VDAC study measured the explicit awareness of color-value mappings among 84 individuals who were tested on the standard paradigm. In this study, only 14% of those tested were aware of the stimulus–reward associations (Marchner & Preuschhof, 2018). The low probability that the training phase induces explicit stimulus-reward associations may unmask stimulus-driven effects (i.e. color-driven capture) that are independent of the intended stimulus values.

Humans and non-human animals are highly adept at learning associations between rewards and the cues that signal their availability. In the VDAC paradigm, however, multiple factors change on a given trial. When polled for awareness of patterns related to the monetary feedback during the training phase, individuals commonly attribute the variability in the monetary values to their own behavioral variability (e.g. speed to respond, number of correct responses in a row), to other factors that vary across trials (line orientations, side of the screen the target is located on) or participants claim to have actively averted their attention from the inter-trial reward feedback in efforts to "stay focused on the line orientation task" (DiBartolo, et al., in prep.). Furthermore, the use of strategies to minimize effort during the search tasks is commonly acknowledged by participants, including ignoring everything in the display other than the vertical or horizontal line (the only information actually needed to make a response). A strategy like this could lead to the maximization of rewards earned in the training phase, but also minimize the associative learning between the colors of the stimuli and the relative monetary values. Additionally, the training phase is very similar in the critical test of attention capture and observed capture may be the result of a failure to update task rules or to "switch" into a new cognitive state to succeed in the new visual search task.

The VDAC task is complex and confounds numerous Pavlovian and instrumental contingencies in the association between the colors and rewards during training. To address this issue, other researchers studying attention capture have begun testing alternative training techniques that are more in line with the Pavlovian conditioning paradigms used to measure incentive salience attribution in animal models. One procedure, referred to as value-modulated attentional capture or "VMAC," has been adapted with the goal of serving as an analogue for "sign-tracking" in human attention, (Le Pelley et al., 2015). Briefly, participants search a visual display for a diamond among circles and are rewarded for rapidly responding to the target (points based on response speed are later converted to monetary bonuses). On some trials, one of the non-target shapes was a color singleton (an orange or blue, or green or pink circle among grey circles). These colors were associated with the likelihood of a high- or low-value multiplier of the speed-based points. The basic finding was that high-value colored-stimuli slow performance relative to low-value colored-stimuli, even though response slowing is directly counterproductive to reward maximization.

Like VDAC, VMAC has been extended outside of the basic selective attention literature to clinically relevant domains. Albertella et al. (2019) recently found evidence of persistent VMAC in high-risk vs. low-risk alcohol users (as classified by the Alcohol Use Disorders Identification Test (AUDIT); Saunders, Aasland, Babor, De la Fuente, & Grant, 1993). During a stimulus-reward contingency reversal, individuals with riskier patterns of alcohol-use exhibited persistent VMAC while low-risk individuals did not (Albertella, Watson, Yucel & Le Pelley, 2019). Because these value-associated stimuli in the VMAC paradigm predicted reward magnitude, but were not instrumental in acquiring the rewards, it is thought that they have a Pavlovian relationship with reward. However, an important factor that weakens this claim is that during the instruction portion of the VMAC experiment, participants are explicitly informed of the color-value mappings. Explicit instructions could induce “one-shot learning,” which may rely on different neural processes than incremental learning which involves uncertainty about causal relationships (Lee, O’Doherty & Shimojo, 2015). Furthermore, though colors were assigned to various value and reversal conditions across subjects, no color-value interactions were tested. The results presented in Chapter 3 show that this factor is important to consider in visual search paradigms measuring attention capture by colored stimuli that were assigned a value-association. Like VDAC scores, the range of VMAC reversal scores presented in the aforementioned study was not restricted to positive values that one might expect "distractor" costs to induce; a large portion of the participants were *faster* in the presence of reward-associated distractors.

The paradigms discussed in the sections above were developed in the human selective visual-attention research domain to study the effects of associative learning on the prioritization of valuable stimuli. Recently, there have also been attempts to establish the translational relevance and ecological validity of animal autoshaping paradigms in human research subjects. For example, Wardle, Lopez-Gamundi & Flagel (2018) presented human participants with images that predicted small food rewards delivered through a rotating delivery door. Following a conditioning session, measures of arousal were significantly greater for the CS (images) than US (food), however participants did not report the CS image to have appetitive value greater than that of a neutral image and the behavioral measures were not consistently correlated with other measures of attentional bias or impulsivity. However, there were some key differences from the typical conditioning box set-ups that rodent experiments use. Whereas the rodents are typically presented with an interactable "sign" such as a lever, the human participants were passively exposed to neutral scene images on a computer screen. The interactable nature of the sign stimulus may be necessary to produce measureable motivational salience. In the current study, we used interactive eye tracking to test Pavlovian conditioned approach in healthy young-adults and subsequently measured attention capture by the previously relevant conditioned stimuli.

4.1 Experiment 10: Incentive salience attribution in human sign- and goal-trackers

Methods

Participants

Undergraduate students from the Johns Hopkins University were recruited to participate for extra class-credit. During the informed consent process, participants were informed that, in addition to class credit, they could earn monetary bonuses during the experimental task. We tested 42 young adults (Age: 19 ± 1; 11 Male). All participants had normal or corrected to normal visual acuity and normal color vision.

Procedures

Autoshaping task

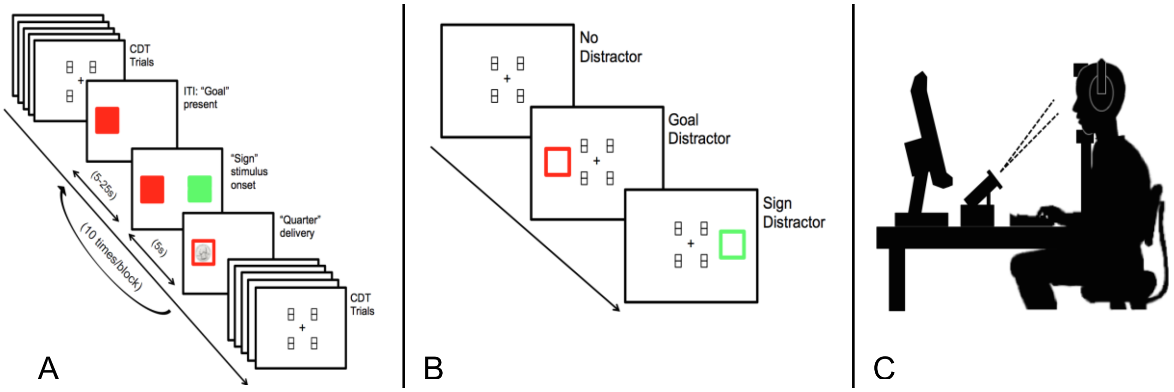

Figure 11. Experiment 10 task designs & stimulus presentation apparatus. A. Conditioning Task. B. Attention bias task. C. Participants were seated in front of the stimulus display computer with their face in a chin & forehead rest. Eyelink 1000 table mount was used to track eye-movements and participants responded to task demands using eye-movements and keyboard presses.

Autoshaping occurred over 4 blocks of 10 trials (Figure 11A). At the beginning and end of each block, participants completed 5 practice trials of a centralized discrimination task (described in detail in the following section). During conditioning, a framed box served as a “goal” stimulus. The framed box was either red (255, 0, 0) or green (0, 255, 0) and located on either the left or right side of the screen (both factors counterbalanced). The goal stimulus was continuously present throughout each conditioning period. If participants made an eye movement into the goal stimulus, the color of the framed box filled in. After a varying amount of time (randomized ITI between 5 – 25 seconds) a separate "sign" stimulus appeared for five seconds on the opposite side of the screen. If participants made an eye movement into the sign stimulus, the half of the framed box that the XY coordinate of the eye was located in filled in and a "clicking" sound was produced. Participants could cause the color to flicker up and down within the sign stimulus and produce auditory and visual feedback on the screen in real time based on their eye movements. Regardless of participant behavior during the presentation of the sign stimulus, five seconds after the onset, the sign stimulus disappeared and was followed immediately by delivery of monetary reward (image of a quarter) at the goal location along with the sound of a "coin drop." To obtain the quarter reward, participants had to fixate on the quarter and press the space bar on the keyboard. Upon quarter retrieval, a "cha-ching" noise was produced.

Throughout the conditioning blocks, we measured the amount of time participants spent dwelling in the sign or goal locations (dwell time), the number of times they entered the regions (entries), and the number of movements made within each region (contacts). We used a Pavlovian conditioned approach index (PCA; Meyer, Lovic, Saunders, Yager, Flagel, et al., 2012) to classify individuals as "sign-trackers" or "goal-trackers" based on their behavior during the autoshaping task. The PCA index score accounts for three measures of approach behavior during the 5 second period where they are both present: 1) Response Bias: the ratio of sign contacts and goal contacts in relation to the total number of responses, [(total sign-directed contacts - total goal-directed contacts)/(sum of total contacts)], 2) Probability Difference: the difference between the probability of entering the sign region and goal region [probability of sign entry - probability of goal entry], and 3) Dwell Time: the difference between the amount of time spent in the location of the sign or the goal [(goal dwell time – sign dwell time)/5]. These three values are then averaged together to provide a PCA Index score ranging from +1.0 to -1.0. PCA Index scores ranging from -1.0 to 0 were classified as goal-trackers (GTs) and scores ranging from 0 to +1.0 were classified as sign-trackers (STs).

Attention bias task

The autoshaping task was immediately followed by a centralized discrimination task (CDT) implemented to assess attentional biases (Cunningham & Egeth, 2017). Four masked stimuli appearing as digital 8s were presented in a matrix around a central fixation cross. The fixation-cross subtended 0.5° of visual angle vertically and horizontally. Each of the four stimuli was positioned in one of four quadrants around the fixation cross (Figure 11B). The distance from fixation to the nearest part of a stimulus was 1.2° of visual angle. Stimuli subtended 0.5° by 0.8°. In ordinary reading order, two sections were removed from each 8, revealing either a "2" or a "5." Participants identified whether each stimulus was a "2" or a "5" by pressing the "g" or "h" key on the keyboard, respectively, responding as quickly as possible while also trying to be accurate. Half of the trials included a distractor stimulus, either the framed box sign (1/4th of trials) or goal (1/4th of trials) stimulus from the autoshaping task. These images subtended 5° horizontally and 5° vertically. When a distractor image was presented, it appeared for a brief time (125 milliseconds), simultaneously with the unmasking of the second, third, or fourth item in the matrix. We categorized trials into three types: “sign” distractor present, “goal” distractor present, and distractor absent. We used response times on distractor absent trials as a reference point and subtracted those response times from the response times for the equivalent lag and position in each of the distractor present conditions to calculate RT costs.

Questionnaires:

Participants completed a battery of computerized self-report questionnaires at the beginning of each testing session using Qualtrics. This battery included the Behavioral Inhibition System/ Behavioral Activation System Scales (BIS/BAS; Carver et al., 1994), the Barrett Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995), and the Barkley Adult ADHD Rating Scale IV (BAARS-IV; Barkley, 2011). Following completion of all other procedures, participants filled out a paper and pencil questionnaire about the behavioral tasks. Participants were asked to rate how much they liked to interact with each of the stimuli and how engaged they were during the tasks using a 1-9 point Likert scale. They were also provided with space to answer an open-ended question about general strategy usage.

Equipment

Stimulus presentation was controlled using the Psychophysics Toolbox running in Matlab (Brainard 1997). Eye position was monitored throughout the experiment using an Eyelink 1000 (table mount). Eye position data were collected at a sampling rate of 1000 Hz. We conducted a 5-point calibration routine for the eye tracker prior to the start of each run.

Results

Autoshaping: We used the standard Pavlovian conditioned approach index to classify individuals as sign-trackers (N=34) and goal-trackers (N=8). Upon sign-stimulus presentations, sign-trackers rapidly interacted with the cue and fixated in the region of the stimulus during its presentation, whereas goal-trackers instead spent the duration fixated in the goal region. Sign- and goal-tracking behaviors did not depend on the color- or location assignments counterbalanced across participants.

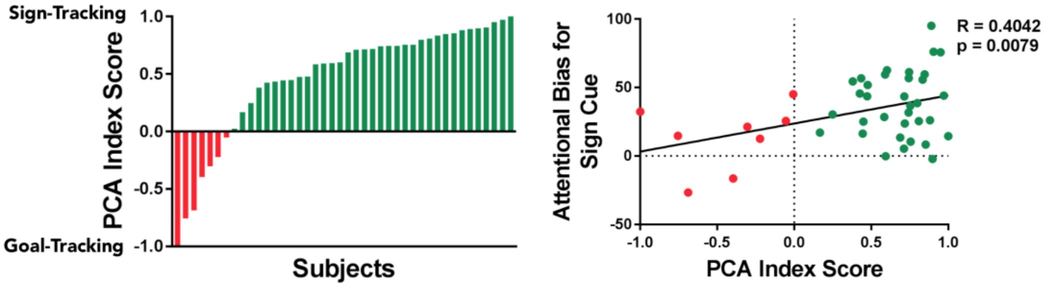

Figure 12. Experiment 10 Results. A) Pavlovian Conditioned Approach (PCA) Index Scores from the autoshaping task. B) Correlation between PCA index score and the attention bias magnitude for the sign stimulus.

Attention bias: We subtracted the average RT on each distractor present condition from the distractor absent condition. Both the sign stimulus, t(41) = 8.5, p < .001 and goal stimulus, t(41) = 6.6, p < .001, induced significant RT costs. The difference in sign- and goal-RT costs did not significantly differ at the group level t(41) = .89, p =.375. Next we compared the RT cost for the sign and goal stimuli to the PCA index scores. The PCA index scores were correlated with attention bias magnitude for the sign stimulus (r = .4042, p = .0079), but not the goal stimulus (r = .1647, p = .2974). Attention bias scores did not depend on the color- or location-assignments counterbalanced across participants.

Questionnaires: Average Likert values for the survey battery and follow-up questionnaires are reported in Table 5. We compared responses in the initial battery of questionnaires to the PCA index. The behavioral inhibition scale was correlated with the

PCA index score (r = -.3145, p = .0425), indicating that lower inhibition is associated with greater sign-tracking behavior. The PCA index score was also correlated with the "Cognitive Complexity" subscale of the BIS-Impulsivity Scale (r = -.4436, p = .0033). This subscale measures tendency to think about complex thought problems, think about the future and like solving puzzles. Participants with more impulsive tendencies related to cognitive-complexity were more likely to exhibit sign-tracking tendencies. All other correlations between the PCA index scores and personality questionnaires were not significant.

Next, we compared the PCA index score to the responses in the follow-up survey. The PCA index score was correlated with the self-reported "Liking" of the sign stimulus (r = .3828, p = .0123), but not the goal stimulus (r = -.2490, p = .1118).

Table 5: Experiment 10 Results.

Demographics & Questionnaires	
Measure	*M (SD)*
N	42
Gender (% Female)	74
Age	19 (01)
BIS-11 Impulsivity	62 (08)
Barkley ADHD	23 (03)
BIS Inhibition	23 (03)
BAS Approach	39 (04)
AS Engagement	07 (01)
AB Engagement	06 (01)
AB Motivation	06 (02)

Autoshaping	Sign	Goal
Measure	*M (SD)*	*M (SD)*
Dwell Time (s)	1.42 (0.56)	0.55 (0.49)
Entries	8.04 (3.60)	1.28 (1.12)
Contacts	15.8 (7.20)	3.94 (2.82)
"Liking"	6.14 (2.27)	4.60 (2.19)

Attention Bias	Sign	Goal
Measure	*M (SD)*	*M (SD)*
RT Cost	33.30 (25.40)	29.15 (28.65)

Note: Mean (*M)* and standard deviation (SD) values rounded to the nearest integer. Acronyms: BIS-11: Barrett Impulsivity Scale, version 11; BIS: Behavioral Inhibition System; BAS: Behavioral Activation System; AS: Autoshaping; AB: Attention Bias; RT: Response Time.

We calculated the degree to which participants “liked” interacting with the sign-stimulus vs. goal-stimulus by subtracting the respective Likert scores. This difference in sign- vs. goal- “Liking” was significantly correlated with the PCA index score, (r = .4393, p = .0036).

Discussion

Individuals differ in their attribution of motivational value, also referred to as incentive salience, to reward-paired cues. While previous studies have established that animal sign-trackers are prone to addictive behaviors (Saunders et al., 2011) and impulsivity (Tomie et al., 2008), few studies have examined individual differences in incentive salience attribution in human populations using paradigms that are analogous to those used in animal models. In the current study, we found the majority of participants exhibited sign-tracking behaviors, spending time interacting with a reward-predictive cue despite lack of any instrumental contingencies. We found that sign-tracking behavior predicted subsequent attentional biases, even when the sign-cue was task-irrelevant. Furthermore, lower self-reported inhibition and greater impulsivity tendencies were associated with increased sign-tracking behavior during conditioning while lower drive to accomplish goals was associated with increased RT costs in the presence of “sign” distractors.

Experiment 10 represents a first step toward adapting animal model-based autoshaping paradigms for use in human participants using dynamic, interactive visual feedback. Though we observed significant correlations with behavioral and self-reported measures, we were limited in our ability to directly compare measures between the sign-tracking and goal-tracking groups, given the imbalance in the number of participants in each category. Future studies could include an initial testing session to determine PCA scores and then recruit equal numbers of participants to return for attention bias testing and other follow-up measurements. Finally, several important outstanding questions remain to be addressed to validate the current paradigm and establish the dependence of the findings on the reward-history imbued in the conditioning phase. For example, it is unclear whether the sign-tracking behavior observed in the current study is driven by the predictive value of the sign-stimulus or the interactive nature of the stimulus. Future studies could include an interactive stimulus that is not paired with reward to disentangle these components.

Conclusions

In the current study, we found humans exhibit trait-like sign- or goal-tracking behaviors analogous to those observed in animals. The majority of participants in our sample exhibited “sign-tracking” behavior, rapidly and vigorously interacting with the reward predictive cues during their presentation. We found that the degree to which humans sign-track during conditioning predicts the magnitude of subsequent attention capture by previously rewarded cues. These data indicate that humans differ in their propensity to attribute reward-paired cues with incentive salience and that the degree to which they do so has implications for the capture of attention by previously rewarded cues.

Chapter 5

Stable reward cues drive counterproductive reward-seeking behavior

Everyday life requires continuous juggling of multiple priorities that demand attention across various time scales. Given limited resources to attend to multiple priorities, over-attending to a given priority often comes at the expense of under-attending to others. Continuation of a pattern of behavior despite the harm it causes is a component of the definition of addiction (Sussman & Sussman, 2011). However, the transition from normal to pathological patterns of behavior is not the result of any single instance. Many individuals experiment with or regularly engage in behaviors for which others develop addictions (e.g. from video-gaming to substance use; Chamberlain, et al., 2016).

Conflict arises when the goals of an agent do not align with the environmentally prompted behaviors induced by cue-exposure. It's difficult to maintain progress toward goals like keeping a diet or exercise plan when there are alternative attractive options available. It is well known that goal setting does not always align with behaviors that prompt goal attainment. In a study on New Year's resolutions, in which a person resolves to change an undesired trait or behavior or accomplish a personal goal, Norcross & Vangarelli (1989) tracked the progress of 200 resolvers. They found that while 77% percent of individuals maintained their pledges for one week, only 19% maintained their pledges over a two-year period. Predictors of lapse and relapse in both dieting (Karlsson, Hallgren, Kral, Lindross, Sjostrom & Sullivan, 1994) and addiction (Smyth et al., 2010) often include stress or negative affect and exposure to conditioned cues or contexts.

In addition to the previously discussed models of cue-reactivity and extinction, a model that has gained popularity in the human addiction literature in recent years is referred to as Pavlovian to Instrumental Transfer, or PIT. PIT has been observed across a variety of species including mice, monkeys, pigeons, rabbits, rats and humans (See Holmes, Marchand & Coutureau, 2010 for review). In the PIT procedure, two stimuli are paired with distinct rewarding outcomes through Pavlovian conditioning, and separately, two instrumental responses are trained for the same outcomes. In a transfer test, the stimuli are presented in a context where the instrumental responses can be carried out. A PIT effect is demonstrated when presentation of each Pavlovian conditioned stimulus selectively enhances the respective instrumental responses. Recently, PIT has been examined in typical adult populations with varying levels of substance dependence. For example, Hogarth et al., (2014) measured the extinction of cue-evoked drug seeking in adult smokers and alcohol drinkers. They found that degrading the hierarchical expectations of reward availability (i.e. "if this cue is present and I take action, then I get rewarded"), either by discriminative extinction training or explicit instructions that this contingency was no longer valid, abolished drug-seeking responses.

In paradigms modeled after extinction-based learning, experiments typically manipulate the availability or probability of obtaining rewards given the presence of a cue. However, in real world settings, the relationships between cues and the stimuli they are associated with are often stable and do not change when the goals of the agent do, such as in an attempt to remain absenent. Furthermore, as long as an individual has capabilities for either mobiliity or communication with another mobile individual, rewards are often constantly attainable. The current design aimed to measure one of the common consequences of having problems balancing priorities when there are valid, reward-associated opportunities signaled in the environment that conflict with goal-driven behavior (i.e. "dropping the ball").

When negative consequences accumulate based on persistence of maladaptive behaviors interfering with other priorities, individuals sometimes seek out intervention programs (HHS, 2016) or are mandated by the criminal justice system to complete them (Coviello, et al. 2013). Behavioral interventions vary in degree of effectiveness based on factors like progress tracking and individualized feedback. In a recent meta-analysis on the effects of outcome tracking and feedback on diet maintenance in a group of diabetic individuals, it was observed that physically recording progress towards goals and the presentation of that progress in social settings led to better diet plan adherence and successful outcomes compared to individuals who were simply enrolled in a program (Harkin et al., 2016). Based on the previous findings regarding the effectiveness of intervention techniques, we also tested the influence of providing regular feedback to participants about the consequences of their behavior in the current study.

5.1 Experiment 11: A measure of "dropping the ball"

We developed a new computerized measure to evaluate the persistence of cue-evoked reward-seeking behaviors despite goal- and reward-related consequences. On each trial, participants responded by moving the mouse cursor to hit a falling target before it reached the bottom of the task area on the screen. Every few trials the availability of a monetary bonus was signaled by the appearance of a salient peripheral cue. To obtain the bonus money, participants had to leave the primary task area where the target was falling and perform a sequence of mouse clicks and button presses. Performing this sequence of actions while the bonus cue was present always led to earning the bonus, as long as participants returned to the primary task area and hit the falling box before it reached the bottom. Rather than changing the relationship between the cue and reward, we increased the difficulty in hitting the falling target by increasing the drop speed over time. We predicted that participants would continue to pursue bonuses, even when that pursuit directly conflicted with the goal of never letting the box fall, and even if this pattern of behavior would no longer lead to successful procurement of bonuses.

Methods

Participants

Participants between the ages of 18-35 with normal or corrected-to-normal visual acuity and normal color vision were recruited from the Johns Hopkins Community. A total of 83 participants completed the study (27 Male, 1 Non-Binary, 55 Female, Mean Age = 23.17 (4.53 SD). Testing sessions lasted 45 minutes to an hour.

Questionnaire

Following completion of the experimental task, a paper and pencil follow-up questionnaire was administered. The follow-up questionnaire assessed task engagement, motivation, "liking" to interact with the falling box, "liking" to interact with the bonus cue, "wanting" to interact with the bonus cue, and confidence in interacting with the bonus cue. Answers were provided through Likert Scale rankings from 1: "Not at all" to 9: "Extremely" for each round of the task.

Task-Paradigm

The primary task area was presented as a black box surrounded by a gray border at the center of the screen (See Figure 13). Each trial was preceded by a 3, 2, 1 countdown (each number presented centrally for 500 ms). Following the countdown, a small white box appeared at the top of the primary task area in one of 10 locations equally spaced across the top border (location randomly determined each trial). Upon appearance, the box began to gradually fall towards the bottom of the area. If the white box reached the bottom of the black primary task area, that trial was coded as an error.

Instructions

Before starting the task, participants were asked to prioritize the overarching goal of never letting the box fall to to the bottom of the primary task area. To progress through the levels of the task, participants moved the mouse to guide the cursor (gray circle in Figure 13) to hit the falling target (white box in Figure 13) before it hit the bottom boundary of the primary task area on each trial. Each time a target was hit, participants earned a point. Progress toward level completion was incremented on a point bar to the left of the primary task area. When the point bar for a level was filled, the task progressed to the next level where the drop speed of the primary task target increased. Every five trials, a cue that signaled a bonus opportunity was presented outside of the main task area. To collect the monetary bonus (e.g. 5 cents) participants had to complete a series of steps: (1) click the mouse while the cursor is inside of the primary task area to “break” the gray border (2) move the cursor to the bonus cue (3) click on the bonus cue (4) move the cursor over the nickel presented in the bonus area (5) hit the space bar button on the keyboard and (6) move the cursor to hit the falling target before it hit the bottom boundary of the primary task area. If this series of steps was completed, five cents was added to the participants' actual compensation total for the experiment. If the primary task of hitting the falling box was not completed, the participant did not earn the trial point or monetary bonus on that trial. Missing a falling box also came with the additional consequence of increasing the overall time on task.

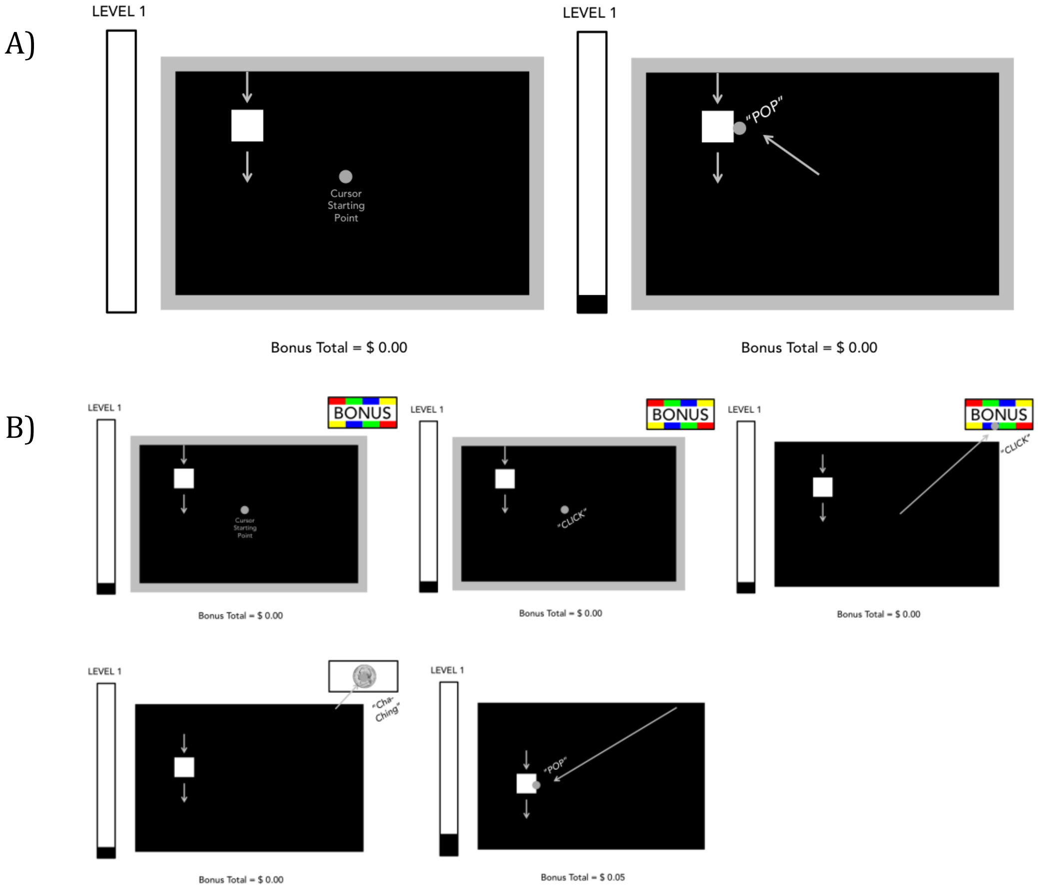

Figure 13. Experiment 11 task paradigm. A) Non-bonus trial action sequence. B) Bonus trial action sequence (EARN feedback group).

Feedback

Participants were assigned to one of three feedback groups. One group was provided with feedback each trial tracking how much bonus money they had earned (group EARN), one group was provided with feedback each trial tracking how many falling boxes they had missed (group MISS) and one group did not receive trial level feedback regarding bonuses or missed boxes (group NONE). The groups did not differ in age or gender distribution.

Design

The task consisted of 25 levels, including five practice levels at the beginning of the task. Levels 1-5 were considered “practice” because the speed at which the falling box dropped was extremely slow, however bonuses could be accrued during this period of the task as well. With the box falling slowly, there was ample time to complete the bonus task before the primary target neared the bottom boundary. As the levels progressed, the drop speed increased and the difficulty of completing the task increased. Levels were completed in rounds of five levels each and upon the completion of each round, the task script terminated and participants opened the testing room door to signal the experimenter to begin the next round of trials. The task progress was recorded between each round. The x-y coordinates of the mouse cursor were continuously tracked throughout the duration of the task. Accuracy for the primary task (hitting the falling boxes) was measured on each trial. Repeated measures ANOVAs and Bonferroni corrected post-hoc comparisons were used to test for differences in performance or self-

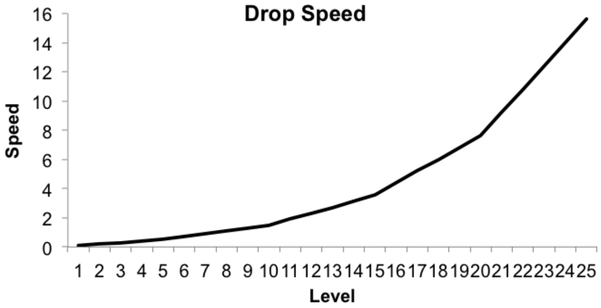

Figure 14. Drop speed. The speed at which the box fell from the top of the screen increased over time through the task levels.

reported measures. Post-hoc comparisons are reported for those tests that indicated significant effects of Feedback group (post-hoc tests that only indicated significant task round-based effects are omitted).

Results

Accuracy

We performed a 2 (Trial type: Bonus vs. Non-Bonus) by 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on accuracy for hitting the falling box on each trial. We observed a main effect of Trial type, $F(1,80) = 320.81$, $p < .001$, $\eta p^2 = .800$, and Bonferroni corrected post hoc comparisons indicated that participants were less accurate when on bonus trials than non-bonus trials, $p < .001$. We also observed a main effect of feedback type, $F(2,80) = 11.29$, $p < .001$, $\eta p^2 = .220$,

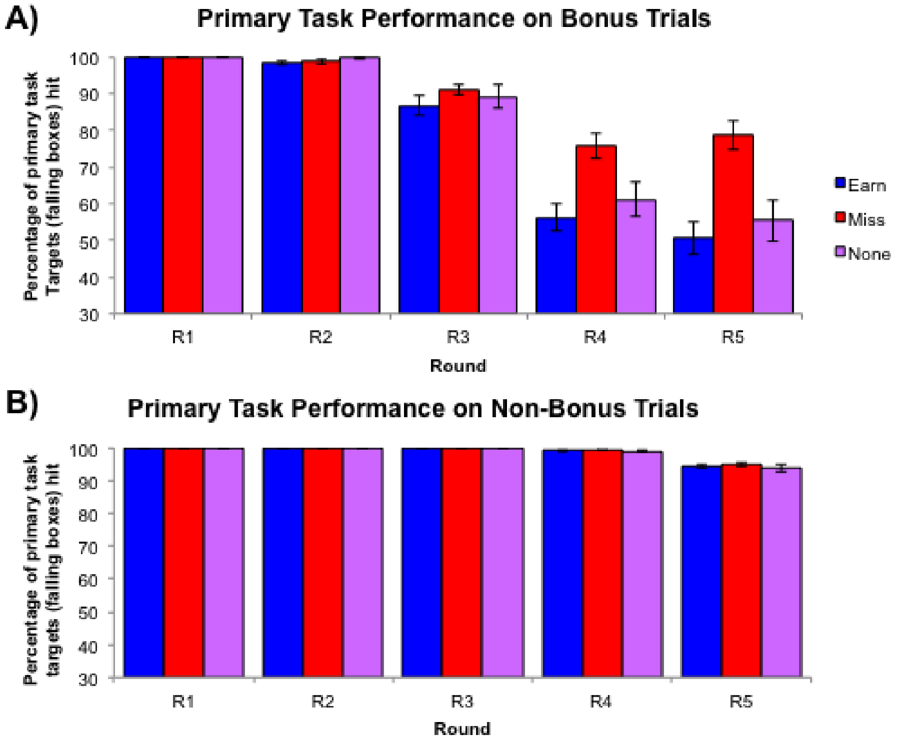

Figure 15. Experiment 11 accuracy results. Accuracy on the primary task (hitting falling boxes) in each round. A) Accuracy on Bonus Trials. B) Accuracy on Non-Bonus Trials.

and Bonferroni corrected post hoc comparisons indicated that the MISS feedback group was more accurate than the EARN ($p < .001$) or NONE feedback groups ($p = .004$). The EARN and NONE feedback groups did not differ in accuracy, $p = .894$. Additionally, there was a main effect of Round, $F(4,320) = 160.64$, $p < .001$, $\eta p^2 = .668$, participants declined in accuracy over the course of the rounds. Finally, there was a 3-way interaction, $F(8,320) = 5.577$, $p < .001$, $\eta p^2 = .122$ between the factors (All two-way interactions significant, $Fs > 6$). The difference in the bonus-related accuracy decline over the course of rounds depended on feedback group (See Figure 15 and Table 6).

Engagement

We performed a 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on reported task engagement. We observed a main effect of round, $F(4,320) = 6.669$, $p < .001$, $\eta p^2 = .077$, but no main effect of feedback type, $F(2,80) = 1.234$, $p = .297$ or interaction between the factors, $F(8,320) = .498$, $p = .687$, $\eta p^2 = .012$.

Motivation

We performed a 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on reported task motivation. We observed a main effect of round, $F(4,320) = 7.756$, $p < .001$, $\eta p^2 = .088$, but no main effect of feedback type, $F(2,80) = .987$, $p = .377$ or interaction between the factors, $F(8,320) = .927$, $p = .430$, $\eta p^2 = .023$.

"Liking" to interact with the falling box

We performed a 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on reported "liking" to interact with the falling box. We observed a main effect of round, F(4,320) = 6.721, $p < .001$, $\eta p^2 = .078$ and a main effect of feedback type, F(2,80) = 3.53, p = .034, but no interaction between the factors, F(8,320) = 1.625, p = .189, $\eta p^2 = .039$. Bonferroni corrected post hoc comparisons indicated that the EARN feedback group liked to interact with the falling box significantly less than the NONE feedback group (p = .046), but not the MISS feedback group (p = .107). The EARN and NONE feedback groups did not differ.

"Liking" to interact with the bonus cue

We performed a 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on reported "liking" to interact with the bonus cue. We observed a main effect of round, F(4,320) = 97.663, $p < .001$, $\eta p^2 = .550$ and a main effect of feedback type, F(2,80) = 4.599, p = .013, but no interaction between the factors, F(8,320) = 1.446, p = .229, $\eta p^2 = .035$. Bonferroni corrected post hoc comparisons indicated that the MISS feedback group liked to interact with the bonus cue significantly less than the NONE feedback group (p = .018), but not the EARN feedback group (p = .067). The EARN and NONE feedback groups did not differ.

"Wanting" to interact with the bonus cue

We performed a 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on reported "wanting" to interact with the bonus cue. We observed a main effect of round, F(4,320) = 60.310, $p < .001$, $\eta p^2 = .443$ and no main effect of feedback type, F(2,80) = 1.810, p = .170. However, we observed an interaction between the factors, F(8,320) = 2.102, p = .035, $\eta p^2 = .051$. The MISS group declined in "wanting" by the end of the task more than the EARN or NONE groups.

Task Confidence

We performed a 3 (Feedback type: EARN vs. MISS vs. NONE) by 5 (Round: 1-5) repeated-measures ANOVA on reported "confidence" in ability to interact with the bonus cue. We observed a main effect of round, F(4,320) = 370.981, p < .001, $\eta p^2 = .823$, a main effect of feedback type, F(2,80) = 3.131, p = .049, and an interaction between the factors, F(8,320) = 3.411, p = .001, $\eta p^2 = .079$. By the last round, the EARN group was more confident than the NONE group and the NONE group was more confident than the MISS group.

Table 6: Descriptive Statistics for Experiment 11.

	Round 1 *M (SD)*	Round 2 *M (SD)*	Round 3 *M (SD)*	Round 4 *M (SD)*	Round 5 *M (SD)*
Accuracy					
Bonus					
NONE	100.0 (0.0)	99.68 (1.1)	89.28 (16)	61.08 (23.8)	55.48 (28.4)
EARN	100.0 (0.0)	98.34 (3.12)	86.76 (15)	56.28 (20.4)	50.55 (24.5)
MISS	100.0 (0.0)	98.76 (3.23)	91.17 (7.4)	75.69 (17.8)	78.76 (21.6)
Non-Bonus					
NONE	99.96 (0.2)	100.0 (0.0)	100.0 (0.0)	98.96 (1.77)	93.72 (5.31)
EARN	100.0 (0.0)	100.0 (0.0)	99.97 (.19)	99.10 (1.29)	94.41 (3.80)
MISS	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)	99.41 (0.73)	95.07 (3.67)
Questionnaires					
Engagement					
NONE	7.40 (1.94)	8.08 (1.61)	8.25 (1.15)	8.20 (1.47)	7.88 (1.69)
EARN	6.76 (1.90)	7.34 (1.59)	7.90 (1.08)	7.86 (1.16)	7.31 (1.91)
MISS	7.17 (2.17)	7.45 (2.11)	7.83 (1.44)	8.17 (1.14)	7.90 (1.52)
Motivation					
NONE	7.76 (1.81)	8.08 (1.58)	8.28 (1.34)	8.12 (1.27)	7.56 (1.78)
EARN	7.55 (1.90)	7.93 (1.73)	8.17 (1.04)	7.55 (1.76)	6.48 (2.26)
MISS	7.41 (1.82)	7.69 (1.49)	8.03 (1.27)	7.72 (1.13)	7.24 (1.94)
Liking_$_{\text{Falling Box}}$					
NONE	7.84 (1.77)	8.08 (1.58)	7.84 (1.80)	7.52 (2.12)	7.00 (2.45)
EARN	6.66 (2.07)	6.83 (2.00)	6.97 (1.86)	6.17 (2.27)	5.59 (2.78)
MISS	6.31 (2.21)	6.59 (2.06)	7.03 (2.03)	6.55 (2.13)	6.55 (2.25)
Liking_$_{\text{Bonus Cue}}$					
NONE	8.16 (1.93)	8.56 (1.36)	8.04 (1.57)	6.44 (2.75)	5.12 (3.19)
EARN	8.24 (0.99)	8.24 (0.87)	8.00 (1.20)	6.28 (2.76)	4.31 (2.80)
MISS	7.66 (1.97)	7.69 (1.91)	7.24 (1.90)	4.59 (2.51)	3.10 (2.53)
Wanting_$_{\text{Bonus Cue}}$					
NONE	8.21 (2.02)	8.79 (1.02)	8.42 (1.44)	7.04 (2.31)	5.46 (3.08)
EARN	8.48 (0.91)	8.55 (0.87)	8.41 (0.95)	7.41 (2.38)	5.79 (3.18)
MISS	8.62 (1.35)	8.55 (1.38)	7.90 (1.76)	5.69 (3.15)	4.31 (3.44)
Confidence					
NONE	8.76 (0.83)	8.76 (0.52)	8.12 (1.30)	5.16 (2.54)	3.32 (2.44)
EARN	8.76 (0.51)	8.76 (0.58)	8.24 (0.91)	5.69 (2.16)	2.24 (1.84)
MISS	8.90 (0.41)	8.76 (0.64)	7.38 (1.84)	4.17 (2.30)	1.86 (1.36)

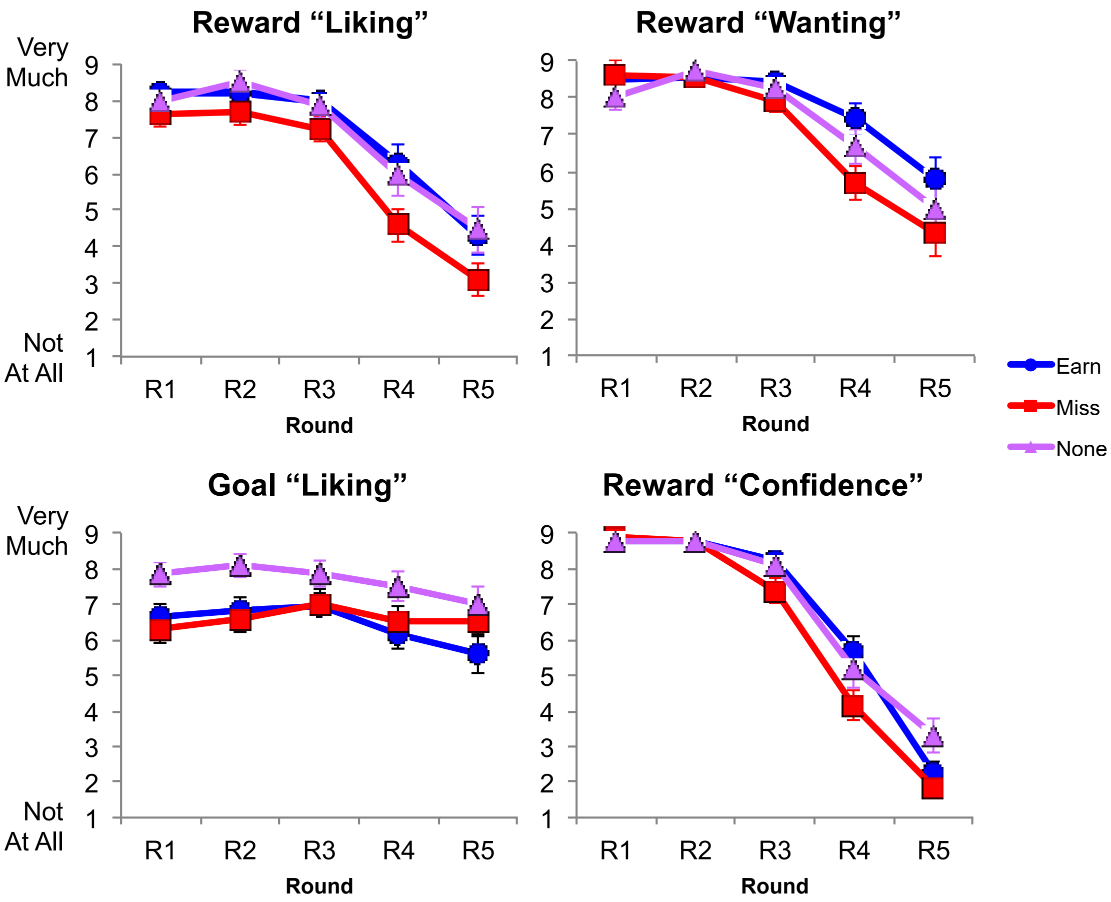

Figure 16. Experiment 11 self-report results. Self-reported follow-up question responses about "liking" and "wanting" and confidence.

Discussion

Following repeated pairings with reward, cues in the environment can signal a predictive relationship with reward and promote subsequent reward-seeking behavior. In the current study, despite the brief time period spent performing the task (approximately 30 minutes) participants rapidly became proficient at acquiring available rewards and continued to carry out reward-seeking behaviors even when they became counterproductive to task goals or reward procurement. We found that participants who were provided trial-level feedback about failures to complete goal-directed behaviors had better task performance than a group that received reward-related feedback and a group that did not receive either of these types of feedback. We also found that providing different kinds of feedback to participants influenced their ratings of "liking" to interact with the primary task stimulus and reward-associated cue. Compared to the group that received no feedback, the group that received positive reward-related feedback "liked" interacting with the *goal-stimulus* significantly less, whereas the group that received negative goal-related feedback "liked" interacting with the *reward-stimulus* significantly less.

Future directions for the current line of studies include (1) assessing individual differences in tendencies to pursue counterproductive bonuses and (2) establishing whether or not this tendency is trait-like, and therefore applicable for testing efficacy of other interventions. As the task progressed in difficulty, the variance in task accuracy increased over time (see Table 6). This variability may provide information about differences in tendency to "let go" of the bonus opportunities and focus on the primary task goals once it becomes too difficult to accomplish both successfully.

The findings of the current study have implications for the design of prevention and intervention techniques. Extant models of the extinction of conditioned responses to reward paired cues typically manipulate the availability of rewards in a given context or change the relationship between the rewards and the cues that they were previously associated with. These stimuli and contexts tend to be highly reliable and valid sources of information about the availability of particular substances. For example, neon "BAR OPEN" signs tend to indicate that entering the sign-bearing establishment and making a payment will lead to the procurement of alcohol. Some prevention guidelines for relapse recommend avoiding the neighborhoods and people that were previously associated with obtaining or using drugs in the past (CDC, 2018). These strategies are simply not realistic options for many individuals (and maybe particularly individuals) with a history of addiction who have economic limitations. Furthermore, in real world settings, individuals addicted to substances of abuse have often learned, over months or years, to associate the reward of the drug with a large set of stimuli, states and contexts, some of which are unavoidable in the long term (e.g. stress). Acknowledgment that substances of abuse (and other bases of addiction) tend to be readily accessible, tend to have stable predictive relationships with the cues that signal their availability and tend to exert powerful control over normal processes of attention and behavior is critical in the development process for prevention and intervention techniques aimed at reducing maladaptive cue-evoked behaviors.

Chapter 6

Conclusions

The consequences of our actions are multifaceted and difficult to fully estimate or track over time. One action that promotes the goals of happiness and sociability (e.g. going to happy hour with friends) may at the same time detract from progress toward goals of productivity and health (e.g. working late or going to the gym). In later stages of addiction, the prioritization of a given stimulus or state is impervious to increases in the magnitude of negative repercussions and decreases in the magnitude of positive repercussions. Behaviors that support the maintenance of addiction commonly do not support abstract goals (e.g. healthiness, happiness) or even concrete goals (e.g. abstinence, productivity).

This dissertation examines the reliability and validity of selective attention paradigms that have been adapted to study biased attentional priorities in humans, investigates the translational relevance of paradigms designed to measure incentive salience attribution in animals, and describes a novel method for measuring biased priorities in the management of multiple goals in dynamic environments. First the reliability and validity of the value-driven attentional capture (VDAC) paradigm was assessed. Across several experiments, poor reliability and multiple indices of poor validity were observed, suggesting this measure is not suitable for estimating individual differences or testing the effectiveness of intervention techniques. Next, the translational relevance of a Pavlovian conditioning task commonly used to train animals to associate rewards with cues and measure incentive salience attribution was assessed using an adapted eye-tracking paradigm. The majority of participants dwelled on and vigorously interacted with reward-predictive cues, indicating cues acquired incentive salience. The degree to which they interacted with the reward-predictive cues was related to the magnitude of attentional capture by these cues in a subsequent selective attention task. Finally, a novel paradigm for assessing behavioral tendencies to pursue reward opportunities, despite the accumulation of negative consequences, was tested. In general, participants persistently attempted to pursue rewards, even when reward-seeking behaviors had negative consequences for progress toward the overarching goals of the task. However this behavior was modulated by negative consequence-related feedback.

Though addiction is a major focus of science, medicine and social services, existing prevention and treatment techniques have poor success rates. With high relapse rates in those attempting to remain abstinent and substance abuse-related deaths on the rise, as well as national economic costs estimated at over $700 billion annually (NIDA, 2017), it is imperative that more effective prevention and treatment techniques be developed. Extant intervention techniques for maladaptive behaviors like addiction have often resorted to removing or devaluing the relationship between cues and desired outcomes in attempts to break habitual response to those cues. However, associations between cues and substances are easy to learn and difficult to forget. Compulsive responsivity to internal or external cues for substance-seeking behavior can come to dominate actions despite the goals to remain abstinent or to initiate other behavior changes. Rather than repeatedly exposing individuals to changes in the validity of a previously established cue-substance association (i.e. cue exposure therapy), therapeutic techniques should consider the stability in validity of cues and the rewards that they predict. Unless the availability of lethal addictive substances (e.g. fentanyl) are somehow eradicated from all non-medical settings and the production of substances with insidious long-term health ramifications (e.g. cigarettes) are stopped altogether, our intervention techniques need to take into consideration the these substances of abuse will continue to be accessible.

Quantifying the repercussions of behavioral patterns may help individuals track their progress towards goals, however there are important considerations that should be taken into account. The ability to predict, target and deploy resources to problems (e.g. disease, suffering, early mortality) is a major goal of research institutes across the world. Recent advances in modern technology and computing capacity have aided in the development of algorithms that make these predictions more realistic than ever. The major proliferation in internet-connected mobile- and wearable-device usage has largely outpaced the regulation of tracking information attained through these devices including (but not limited to) user activity, location, biometrics and demographics. Like our feedback manipulations presented in Chapter 5, this information can help users recognize patterns in their behavior and make informed decisions. Unfortunately, this information can also be used for less altruistic purposes to target individuals and provide personalized content that may bias the information available to them and change their behavior. Interventions for sensitive behaviors that may be useful at the individual level, such as apps or other online assessments should be evaluated for risk potential prior to distribution and use at large scales.

The work presented in this dissertation has implications for the development of prevention, intervention and treatment techniques that could be individualized to address a multitude of addictive behaviors. Individuals with a history of addiction commonly report desire to change behaviors that have become maladaptive, but frequently relapse into past behavioral patterns. Prevention tools that utilize dynamic outcome feedback may help individuals recognize the slow build of consequences that occur when substance abuse conflicts with goals, before later stages of addiction have taken hold.

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Vita

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EDUCATION

Johns Hopkins University, *Baltimore, MD*	Ph.D. In progress
Department of Psychological and Brain Sciences	M.A. 2017
College of Charleston, *Charleston, SC*	B.S. 2012
Department of Psychology	*Magna Cum Laude*

PUBLICATIONS

1. Joseph, J. E., **DiBartolo, M. M.**, Bhatt, R. (2015) Developmental changes in analytic and integrative processes in face perception. *Frontiers in Psychology.* 6:1165.
2. Lal, C., **DiBartolo, M. M.,** Kumbhare, S., Strange, C., Joseph, J. E. (2015) Impact of Obstructive Sleep Apnea Syndrome on cognition in early postmenopausal women. *Sleep and Breathing.*
3. Donohew, L., **DiBartolo, M. M.,** Zhu, X., Benca, C., Lorch, E., Noar, S. M., Kelly, T. H., Joseph, J. E. (2017). Communicating with Sensation Seekers: An fMRI Study of Neural Responses to Antidrug Public Service Announcements. Health Communication, 1–9.
4. Anderson, B. A., Chiu, M., **DiBartolo, M. M.**, Leal, S. L. (2017) On the distinction between value-driven attention and selection history: Evidence from individuals with depressive symptoms. Psych Bull Rev.
5. Wright, J.C., Reinhold, E., Galizio, A., & **DiBartolo, M. M.** (2019) Judge no evil, see no evil: Do people's moral choices influence to whom they visually attend? *Methodological Advances in Experimental Philosophy,* Bloomsbury Publishing, Continuum Press: New York

MANUSCRIPTS (UNDER REVIEW/IN PREPARATION)

1. **DiBartolo, M. M.**, Gmeindl, L., Courtney, S. M. (submitted) Color Drives Capture in the Value-Driven Attentional Capture Paradigm.

2. Jarnecke, A., Flanagan, J., **DiBartolo, M. M**, Nguyen, C., Hill, B., Zhu, X., Anton, R., Joseph, J. (submitted) Greater monetary incentive loss sensitivity and negative affect in high-risk compared to low-risk social drinkers.
3. Vaughan, B., Zhu, X., Kellermann, T., **DiBartolo, M. M.,** Lynam, D. Kelly, T. H. & Joseph, J. E. (submitted) Modulation of fronto-limbic emotional reactivity response by cognition and personality: A developmental study.
4. **DiBartolo, M. M.**, Gmeindl, L., Courtney, S. M. (in prep) On the *lack* of test-retest reliability of value-driven attentional capture.
5. **DiBartolo, M. M.,** Fraser, K., Janak, P., Courtney, S. M. (in prep) Incentive salience attribution predicts task-irrelevant attention biases in human sign- and goal-trackers.
6. **DiBartolo, M. M.**, Courtney, S. M. (in prep) "Can't let it go": the persistence of cue-driven reward-seeking despite goal-related consequences.

PRESENTATIONS

1. Jandhyala, N., **DiBartolo, M. M.,** Gmeindl, L., Courtney, S. M. (2019). Does warning that a stimulus is distracting affect how distracting that stimulus is? Poster presented at the Society for Neuroscience Annual Baltimore Chapter Meeting, *Baltimore, MD.*
2. Jeong, S., Gormley, M., **DiBartolo, M. M.**, Gmeindl, L., Courtney, S. M. (2019). Stress and Working Memory: Choking under Pressure or Rising to the Challenge? Poster presented at the Society for Neuroscience Annual Baltimore Chapter Meeting, *Baltimore, MD.*
3. **DiBartolo, M. M.,** Fraser, K., Nichols, V., Janak, P., Courtney, S. M. (2018). Poster presentation: Society for Neuroscience Annual Meeting, *San Diego, CA.*
4. **DiBartolo, M. M.,** Gmeindl, L. Courtney, S. M. (2017). Individual Differences in Value-Driven Attentional Capture: VDAC magnitude is not a reliable trait measure. Poster presentation: Object Perception, Attention, and Memory (OPAM), *Vancouver, Canada.*
5. **DiBartolo, M. M.,** Courtney, S. M. (2016). Value-Driven Attentional Capture in positive and negative reinforcement contexts. Poster presentation: Object Perception, Attention, and Memory (OPAM), *Boston, MA.*
6. **DiBartolo, M. M.,** Anderson, B. A., Courtney, S. M. (2016). Template Specificity in Loss-Avoidance Value-Driven Attentional Capture. Poster presentation: Society for Neuroscience Annual Meeting, *San Diego, CA.*
7. **DiBartolo, M. M.,** Anderson, B. A., Courtney, S. M. (2015) The Role of Loss Avoidance in Value-Driven Attentional Capture. Poster presentation: Psychonomic Society Annual Meeting, *Chicago, IL.*
8. **DiBartolo, M. M.,** Zhu, X., Schacht, J., Froeliger, B., Anton, R., Joseph, J. E. (2014) Different monetary incentive delay neural profiles in high and low risk social drinkers. Poster presentation: Society for Neuroscience Annual Meeting, *Washington, DC.*
9. Lal, C., Zhu, X., **DiBartolo, M. M.**, Joseph, J. E. (2014) Cognitive Impairment and Obstructive Sleep Apnea Syndrome in early Postmenopausal Women. Poster presentation: CHEST 2014, *Austin, TX.*

10. **DiBartolo, M. M.**, Zhu, X., Joseph, J. E. (2014) Sex Differences in Neural Activation during the N-Back Task. Poster presentation: MUSC Women's Health Research Day, *Charleston, SC.*
11. **DiBartolo, M. M.**, Mathew, A. R., McClernon, F. J., Garland, E., & Froeliger, B. (2013) Sex differences in state-dependent affective brain function and motivations to smoke. Poster presentation: Duke Nicotine Research Conference, *Durham, NC.*
12. **DiBartolo, M. M.**, Davies, F., Benca, C. Kelly, T., Noar, S., Donohew, L., Lorch, B., Joseph, J. E. (2013). Exploring affective response to anti-drug/safe sex media messages among high and low sensation seekers. Poster presentation: MUSC Frontiers in Neuroscience Conference, *Charleston, SC.*
13. **DiBartolo, M. M.**, Davies, F., Gilardi, K., Zhu, X., Clark, J.D., Bhatt, R.S., Ruble, L., Glaser, P., Joseph, J.E. (2012). Orbitofrontal Cortex Volume and Autism Spectrum Disorders. Poster presentation: MUSC Frontiers in Neuroscience Conference, *Seabrook Island, SC*.
14. **DiBartolo, M. M.**, Galizio, A., Reinhold, E., Wright, J.C. (2012) Judge no Evil, See no Evil: People visually attend to the benefactors of their moral judgments. Oral presentation: Experiments on Ethical Dilemmas Conference. *London, England*.

AWARDS

1. 2018 Graduate Research Organization Travel Award
   Johns Hopkins University
2. 2018 Walter L. Clark Service Award
   Psychological & Brain Sciences, Johns Hopkins University
3. 2018 Collaborative Research Award
   Psychological & Brain Sciences, Johns Hopkins University
4. 2017 Collaborative Research Award
   Psychological & Brain Sciences, Johns Hopkins University
5. 2013 First Place Poster Presentation
   19th Annual Duke Nicotine Research Conference, Duke University
6. 2012 College of Charleston Research Presentation Travel Grant
   Experiments on Ethical Dilemmas, University of London

TEACHING EXPERIENCE

1. Stress and Coping: Individual and Family Factors, College of Charleston, Fall 2011
2. Research Methods & Design, Johns Hopkins University, Fall 2016
3. Research Methods & Design, Johns Hopkins University, Fall 2017
4. Functional Neuroanatomy, Johns Hopkins University, Spring 2016
5. Neuroscience of Motivation and Reward, Johns Hopkins University, Spring 2017

COMMUNITY OUTREACH

1. Psychological & Brain Sciences High School Engagement Program (2017-18). Presented information about Psychological and Neuroscience research to high school students from Patterson Park High School. *Baltimore, MD.*

2. Brain Awareness Week (2015-17). Presented information about Psychological and Neuroscience research to high school students at Baltimore Polytechnic High School. *Baltimore, MD.*
3. Ashley Hall Summer Neuroscience Institute: Engaging High School Girls in Neuroscience Research (2014). Presentation Title: Neuroimaging Techniques & Autism Spectrum Disorder. *Charleston, SC.*
4. Ashley Hall Summer Neuroscience Institute: Engaging High School Girls in Neuroscience Research (2013). Presentation Title: Developmental and Translational Approaches in Neuroimaging Research. *Charleston, SC.*
5. Morningside Middle School At-Risk Community Engagement (2013). Presentation Title: Adolescent Drug Use and the Brain. *North Charleston, SC.*
6. Ashley Hall Summer Neuroscience Institute: Engaging High School Girls in Neuroscience Research (2012). Presentation Title: Face Processing & High Sensation Seeking, Perspectives from Neuroimaging. *Charleston, SC.*

SERVICE

1. Lead Coordinator, Graduate Social Event Committee (2016-2019)
2. Lead Organizer, Psychological & Brain Sciences Graduate Recruitment (2016-2018)
3. Representative, Psychological & Brain Sciences Graduate Steering Committee (2015-2019)