

Relating value-driven attention to psychopathology

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Reward-associated objects receive preferential attention, reflecting a bias in information processing that develops automatically following associative learning. Mounting evidence suggests that such value-driven attention operates abnormally in certain psychopathologies, with attentional biases for reward-associated objects being either exaggerated or blunted compared to healthy controls. Here, I review the evidence linking value-driven attention to psychopathology, including drug addiction, depression, attention-deficit hyperactivity disorder (ADHD), compulsivity, and impulsive and risky decision-making. I conclude by offering an integrative framework for conceptualizing the link between value-driven attention and psychopathology, along with suggestions for future research into this burgeoning area of investigation, including research on object attachment.

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The role of reward learning in the control of attention

Perception is a fundamentally selective process. The sensory system of humans and other animals is limited in its representational capacity, such that only a fraction of the information available to perception can be represented at later stages of information processing [1,2]. Attention is the process by which organisms select which objects and events that compete for perception are represented in the brain [2,3].

Given this fundamental limitation, it is important that organisms pay sufficient attention to objects and events that signal the opportunity for reward, lest rewarding opportunities either go unnoticed or be recognized at a moment too late to initiate the actions required to obtain reward [4–6]. Attention can be directed to a stimulus

intentionally based on our goals and intentions, reflecting goal-directed attentional control [1–3]. Although the prospect of reward is known to modulate the goal-directed control of attention when attending to reward-associated stimuli is consistent with task goals, motivating individuals to more strongly prioritize high-value stimuli [7–9], substantial evidence suggests that reward learning can have a more automatic influence on attention as well [see Refs. 4–6 for reviews]. When an object has been learned to predict a reward, this object will distract individuals during visual search [10,11] and observers are more likely to look at the object compared to a neutral or lesser-value stimulus [12–15] even when it is known to be entirely irrelevant to the task at hand and rewards are no longer available. This is referred to as *value-driven attention*, which reflects a biasing effect that reward learning can have on attention allocation, involuntarily shifting attentional priorities in favor of more valuable stimuli [4,5,10]. Such attentional bias is coupled with a bias to engage in approach behavior directed toward the reward-associated object [6,16,17].

This automatic influence of learned value on attention is thought to promote survival and well-being by helping to ensure that rewarding opportunities are quickly detected and less likely to be missed, especially when they appear unexpectedly [4,6]. In this sense, value-driven attention offloads the cognitive burden of having to intentionally search for valuable stimuli in order to detect and respond to such stimuli by automating the process attending to them [4–6,18]. It has been argued that, at least when functioning normally, the benefits of enhanced attention to currently rewarding stimuli conferred by value-driven attention outweigh the negative consequences of having attention temporarily directed to stimuli that were previously but are no longer rewarding, especially if one assumes that stimulus–reward associations tend to be fairly stable in everyday life [4,5].

Although the mechanism of value-driven attention may itself be fundamentally adaptive, it may also be the case that excessive or insufficient attention to reward-associated stimuli could become maladaptive. There is substantial evidence that susceptibility to value-driven attention exists on a continuum, serving as a reliable individual differences measure related to visual working memory and cognitive control [10,12,19**,20**,21] as well as personality traits [10,22–25] and real-world behaviors related to the processing of reward-related stimuli [25]. Recent evidence from individuals who use drugs and patients meeting criteria for drug dependence, individuals with depressive symptoms, children diagnosed with

attention-deficit hyperactivity disorder (ADHD), individuals with high indicators of compulsive behavior, and HIV + patients with a history of risk-taking behavior supports the idea that abnormal sensitivity to the influence of reward on attention is clinically relevant. Below, I review the research linking each of these conditions and behaviors to abnormal value-driven attention, which are addressed in turn.

Relating value-driven attention to psychopathology

Drug addiction

The incentive sensitization theory of addiction posits that drug cues acquire the motivational properties of the drug itself via association, serving as a powerful driver of 'wanting' and corresponding approach behavior [26,27]. One hypothesized component of this cue-elicited wanting is a strong attentional bias toward the cue [24,28]. Consistent with this, a host of studies in individuals who abuse substances and patients meeting criteria for drug dependence demonstrate attentional biases toward drug cues that are not observed in drug-naïve participants [see Ref. 29 for a review].

Value-driven attention shares many similarities with attentional biases toward drug cues [see Ref. 30 for a review], including its resistance to conflicting goals [4,5,10,14], robustness to extinction [31], reliance on striatal dopamine signaling [32–34], and ability to facilitate approach behavior [6,16,17]. Strong attentional biases toward drug cues are associated with drug craving [35,36] and later relapse [37,38]. One possibility, then, is that abnormal sensitivity to value-driven attention more broadly contributes to the development and/or maintenance of an addiction. Research examining patients meeting criteria for drug dependence, individuals with a history of substance abuse, and individuals who heavily use substances supports this idea.

Patients who currently meet the diagnostic criteria for opioid-dependence exhibit an exaggerated attentional bias toward a stimulus feature previously associated with monetary reward compared to matched drug-naïve controls [19**]. Furthermore, in a study of HIV+ patients with a history of risky behavior leading up to contraction of HIV, it was shown that a prior history of substance abuse was similarly associated with stronger attentional bias toward a previously reward-associated stimulus using the same experiment task [20**]. This suggests that the phenotype of drug dependence includes hypersensitive value-driven attention, and that such hypersensitivity does not subside when abstinence is achieved and is instead more trait-like.

Converging evidence for this relationship between addiction and value-driven attention comes from studies of substance use in college-aged samples. Number of illicit

drugs ever used was found to be associated with attentional processing of task-irrelevant cues predictive of high reward, particularly in individuals exhibiting poorer goal-directed attentional control [21]. That is, for individuals who are less able to restrict their attention to goal-related stimuli, greater distractibility by reward-related stimuli is associated with the use of a greater number of illicit drugs [see also Ref. 39*]. Similarly, risky alcohol use was found to be associated with the strength with which attentional capture by learned reward cues persisted into a reversal phase, suggesting that difficulty updating attentional priorities when reward contingencies change is related to substance abuse [40*].

Depression

Blunted reward processing is a well-studied feature of depression [41,42]. Findings suggest that this blunting has consequences for the control of attention. Individuals exhibiting moderate to severe depressive symptoms present with blunted value-driven attentional capture; in fact, attentional bias toward previously reward-associated stimuli could not be detected in such individuals, as if these prior reward cues were completely ignored [43*]. This contrasted with a control group exhibiting minimal symptoms of depression, which presented with typical levels of value-driven attentional capture; moreover, a continuous relationship (significant negative correlation) was observed between the severity of depressive symptoms and the magnitude of attentional bias observed for task-irrelevant but previously reward-associated stimuli [43*]. This suggests that symptoms of depression present with a corresponding reduction in the ability of reward cues to automatically draw attention. It is unclear whether this blunting of value-driven attention reflects a failure to learn the stimulus-reward contingencies of the experiment task or whether it reflects a blunted influence of prior learning on attention; however, the fact that former (rewarded) target colors did not even have a general influence on attentional bias in depressed participants and participants were explicitly informed of the necessity of finding and reporting targets to the receipt of reward during training seems more consistent with the latter [43*].

This blunting of value-driven attention with depressive symptoms also appears to be particular to attention to reward cues rather than a broader deficit in attentional learning. Habit-like attentional biases arising from repeated acts of attentional selection are unimpaired by depressive symptoms, with frequent former-target-color stimuli capturing attention to a robust and comparable degree in depressed and non-depressed individuals [44*]. This sparing of attentional bias arising from reward-independent learning history can be contrasted with the blunted attentional bias toward reward cues in depressed individuals replicated using a reward-based learning task similar to Refs. [43*,44*], indicating a selective deficit in

learned attentional orienting that is more specifically reward-related.

ADHD

One of the hallmarks of ADHD is difficulty with attention regulation and distractibility [45]. Although there is some evidence that the magnitude of value-driven attentional capture is elevated in more impulsive individuals as measured via a questionnaire [10,20^{**},25], individuals diagnosed with ADHD are not necessarily more distracted by task-irrelevant stimuli in general [46]. This latter finding suggests that, in spite of the centrality of attention and distraction to the symptomatology of ADHD, the nature of the associated distractibility is complex.

Somewhat surprisingly, when the magnitude of value-driven attentional capture was compared between children diagnosed with ADHD and matched controls, value-driven attentional capture was found to be less robust and extinguish more rapidly in children with ADHD [47^{**}]. That is, children with ADHD more quickly updated their attentional priorities when previously reward-associated stimuli were no longer rewarded. One potentially important feature of the task used to measure value-driven attentional capture, however, was that accurate performance was rewarded in order to help maintain participant motivation and engagement [47^{**}]. One possible interpretation of these findings, then, is that the attention of individuals with ADHD is driven more strongly by immediate reward considerations at the expense of maintaining long-term stimulus-reward associations, which may be related to the strong tendency in ADHD for individuals to prefer more immediate rewards in a delay discounting task [48]. Several prior studies involving participants who use drugs [21,39^{*},40^{*}] and exhibit compulsive symptoms [39^{*},49] also motivate participants with reward when attentional bias is assessed and observe a different pattern of results with respect to psychopathology; in fact, the degree to which attentional biases fail to adapt to new reward contingencies may be particularly predictive of substance abuse issues [40^{*}]. Furthermore, research using a similar task design in a non-clinical sample demonstrates that the more reward a healthy participant expects is available on the current trial, the more they actually tend to be distracted by previously reward-associated stimuli, suggesting a general facilitatory influence of expected reward availability on value-driven attention [50]. It therefore seems unlikely that the significantly blunted value-driven attention observed in children with ADHD relative to the significantly exaggerated value-driven attention observed in other psychopathologies can be explained entirely by differences in task design, although more research is needed to explore potential interactions between abnormal value-driven attention and different reward contingencies.

Compulsivity

The phenotype of addiction includes compulsive drug-seeking [26,27,39^{*}]. One hypothesis concerning compulsive behavior more broadly is that, although the behavior may be initially driven by anxiety reduction, cues for the initiation of compulsive behavior acquire incentive salience in similar fashion to drug cues [39^{*}]. For example, an individual may begin compulsively hoarding a particular material good to relieve anxiety concerning the possibility of running out of that good, but in doing so, the good is repeatedly associated with the positive experience of anxiety relief and can thereby become an attractive and attention-grabbing stimulus by virtue of this positive association. This hypothesis predicts that susceptibility to attentional capture by reward cues will also be elevated in individuals who struggle with compulsive behaviors not restricted to addiction. This broader relationship between compulsive behaviors and the magnitude of attentional bias toward reward cues has received support in two related studies [39^{*},49].

Impulsive and risky decision-making

In addition to evidence more generally relating value-driven attention to trait impulsivity [10,25], one study has linked value-driven attention to a history of impulsive behaviors leading up to contraction of HIV [20^{**}]. HIV+ participants self-reported impulsive behaviors both at present and leading up to the time at which they contracted HIV. Non-planning impulsiveness at the time of contracting HIV was significantly predictive of the magnitude of attentional capture by learned reward cues, in a manner not explained by current levels of impulsiveness [20^{**}]. This study suggests that susceptibility to value-driven attention is not only related to impulsive behaviors, but also risky impulsive behavior with clinically significant consequences.

Value-driven attention has also been examined in relation to normal development, which offers further insight into its potential link to impulsivity and risk-taking. Adolescence reflects a period of life associated with a pronounced increase in impulsive behavior; it is also associated with elevated susceptibility to value-driven attentional capture compared to young adult participants [51].

Value-driven attention and psychopathology: an integrated framework

Although the research linking value-driven attention to psychopathology is still in its early stages and is somewhat limited in scope, some themes are emerging that may be useful in guiding future research in this area. From this work, it is clear that both atypically high and low sensitivity to the influence of reward on attention is clinically relevant. Susceptibility to value-driven attention exists on a continuum [10,12,19^{**},20^{**},21–25], with moderate levels of attentional bias typically observed in healthy

participants screened for the absence of psychiatric symptoms. Susceptibility to the influence of reward on attention that falls too far above or below this normal level is associated with unhealthy behaviors and psychological disturbance, and the reviewed research offers a glimpse into what the associated syndromes might look like (see Figure 1).

When insufficient attention is directed to reward-related stimuli and events, the individual might neglect opportunities to experience pleasure, with consequences for affect and mood [43°,44°]. As attention gates access to awareness and memory [1–3], positive events will also tend to be diminished when recounting life experiences during the timeframe over which attention is affected, potentially resulting in a skewed perception of the balance of positive and negative experiences and life outcomes. The result resembles the phenotype of depression, and may also contribute to anxiety issues by promoting the false perception of a negatively balanced life in which adverse experiences are more common and severe than they actually are. At the same time, a reduced capacity for past rewards to guide attention based on learned value will potentially render current reward considerations a disproportionately strong driver of behavior [47°], resulting in difficulty maintaining focus toward a longer-term benefit as seen in ADHD.

On the other end of the spectrum, hypersensitivity to the influence of reward on attention could lead to cue-elicited reward seeking that is difficult to inhibit in spite of detrimental consequences [19°,20°,21,39°,40°], as is characteristic of addiction [26,27]. Such unhealthy reward-seeking may not be limited to drug addiction and extend to other addictions and unhealthy habits such as overeating and preoccupation with sex, a possibility

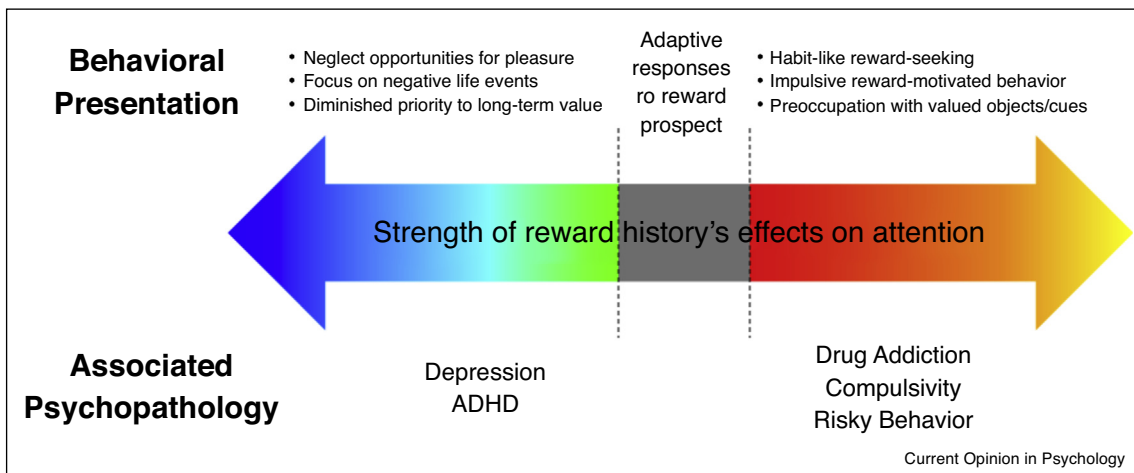
ripe for further investigation. Consistent with this idea, atypically strong value-driven attentional biases are associated with compulsive behaviors more broadly [39°,49], including compulsive drug-seeking [39°], as well as impulsive behaviors related to the contraction of HIV [20°].

Depression can be comorbid with drug dependence and compulsivity [52,53], which on the surface poses an immediate challenge for the proposed framework. In this context, there are two potentially important issues worth considering. The first is that hypersensitivity or hyposensitivity to the influence of reward on attention may confer a risk for developing the associated psychopathologies, but it is not the case that such sensitivity reflects an essential component of any one of these conditions. For example, hypersensitivity may render someone more likely to develop drug dependence, while this same individual can become depressed for reasons unrelated to the control of attention, and vice versa for hyposensitivity to the influence of reward on attention. The second is that the observed relationships may be specific to particular subtypes within a given psychopathology. In the case of addiction, for example, this relationship may be particular to individuals whose drug use is, at least initially, more pleasure-driven.

Potential implications for object attachment and related psychopathology

It could be hypothesized that hypersensitive value-driven attention has consequences for the overprioritization of the value of physical objects, promoting hoarding and/or excessive procurement and accumulation of a particular material good [54]. As with compulsive behaviors more broadly [39°,49], procurement of a particular material good may begin with the desire to relieve anxiety, for

Figure 1



Schematic of the hypothesized relationship between value-driven attention and psychopathology.

example anxiety stemming from the possibility of having an insufficient supply of the object in question. As the procurement of the object is repeatedly paired with the relief of anxiety, the object could itself become associated with value via negative reinforcement. In this way, individuals who are more susceptible to value-driven attentional capture may be more vulnerable to succumbing to a pattern in which the relief of anxiety comes to powerfully bias attention in a manner that perpetuates the associated hoarding behavior [54–56]. Conditions such as compulsive buying disorder [54,57] may be similarly subject to vulnerabilities related to value-driven attention, in addition to the possibility of excessive attention to appetitive reward-related cues such as shopping displays and sale signs that would be consistent with patterns observed in the context of drug addiction and impulsive behaviors [19**,20**,21,39*,40*].

Outstanding questions and future directions

The scope of how value-driven attention is related to psychopathology remains limited to a small number of conditions and problem behaviors, and outside of the context of addiction, each is only supported by one or two studies. A broader picture of the clinical significance of hypersensitive and hyposensitive value-driven attention is needed to refine theoretical models linking the two, and that begins with extending the measurement of value-driven attention to other psychiatric conditions. One particularly fruitful avenue for this further exploration concerns conditions in which object attachment is explicitly implicated, including hoarding disorder and compulsive buying disorder [54–57].

In the context of our extant knowledge, an important question with weighty theoretical implications concerns the order of the relationship between abnormal value-driven attention and psychopathology: which comes first? If abnormal value-driven attention were to follow the development of psychopathology, it would be interesting to explore how it might serve to perpetuate the syndrome by shaping future information processing. Another important question concerns the relationship between value-driven attention and clinical outcomes, and in particular whether abnormal value-driven attention places one at greater risk of a less favorable response to treatment intervention.

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Conflict of interest statement

Nothing declared.

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