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Review

What is abnormal about addiction-related attentional biases?

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ABSTRACT

Background: The phenotype of addiction includes prominent attentional biases for drug cues, which play a role in motivating drug-seeking behavior and contribute to relapse. In a separate line of research, arbitrary stimuli have been shown to automatically capture attention when previously associated with reward in non-clinical samples.

Methods and results: Here, I argue that these two attentional biases reflect the same cognitive process. I outline five characteristics that exemplify attentional biases for drug cues: resistant to conflicting goals, robust to extinction, linked to dorsal striatal dopamine and to biases in approach behavior, and can distinguish between individuals with and without a history of drug dependence. I then go on to describe how attentional biases for arbitrary reward-associated stimuli share all of these features, and conclude by arguing that the attentional components of addiction reflect a normal cognitive process that promotes reward-seeking behavior.

1. The role of attentional bias in addiction

One of the features that characterize addiction is strong attentional biases for drug cues (see Field and Cox, 2008; Rooke et al., 2008; for reviews). When an individual becomes addicted to a substance, stimuli associated with that substance acquire a powerful ability to automatically capture attention that is not evident in individuals without a history of substance abuse (Hogarth et al., 2003, 2005; Lubman et al., 2000; Mogg et al., 2003; Nickolaou et al., 2013a,b; Stormark et al., 1997; see Fig. 1A). Similar attentional biases can also be observed in heavy but non-dependent substance users (Field et al., 2004b; Townshend and Duka, 2001), suggesting that experience with a drug reward creates learning-dependent changes by which associated stimuli become persistently attention-grabbing.

Importantly, there is evidence that addiction-related attentional biases reflect more than just an epiphenomenal curiosity, but rather contribute to the pathology of drug dependence. The magnitude of attentional bias for drug cues has been shown to be predictive of later relapse during the course of treatment (Carpenter et al., 2006; Cox et al., 2002; Marissen et al., 2006; Waters et al., 2003b; Powell et al., 2010), and such attentional biases are thought to mediate the incentive salience of drug cues (Berridge, 2012; Berridge and Robinson, 1998; Robinson and Berridge, 1993). Even after periods of abstinence, attentional biases for drug cues can still be observed (Field and Cox, 2008; Field et al., 2013; Marissen et al., 2006; Stormark et al., 1997), providing a persistent biasing signal that draws the individual to opportunities to experience the drug reward, potentially complicating attempts to maintain abstinence. However, the utility of addiction-related attentional biases as a tool in clinical assessment has not been established (Field et al., 2014), and failures to predict later relapse have also been reported (Field et al., 2013; Waters et al., 2003a).

2. Parallels with normal cognition

In a different line of research using mostly non-clinical samples, attentional biases have been observed for arbitrary stimuli previously associated with non-drug, often monetary, reward (for reviews, see Anderson, 2016a; Awh et al., 2012; Chelazzi et al., 2013). Following a training period in which participants are rewarded each time they locate a searched-for target stimulus, participants complete a test phase in which these previously reward-associated stimuli now appear as task-irrelevant distractors during visual search for a different target. Attention is biased to select such previously reward-associated distractors in this case (Anderson et al., 2011a,b, 2014, 2016c; see Fig. 1B). Similar attentional biases are either not observed or are substantially weaker following otherwise equivalent training in which rewards are not given (Anderson, 2016b; Anderson et al., 2011a,b, 2012, 2014; Failing and Theeuwes, 2014; Wang et al., 2013; Qi et al., 2013); thus, the reward learning imbued associated stimuli with height-

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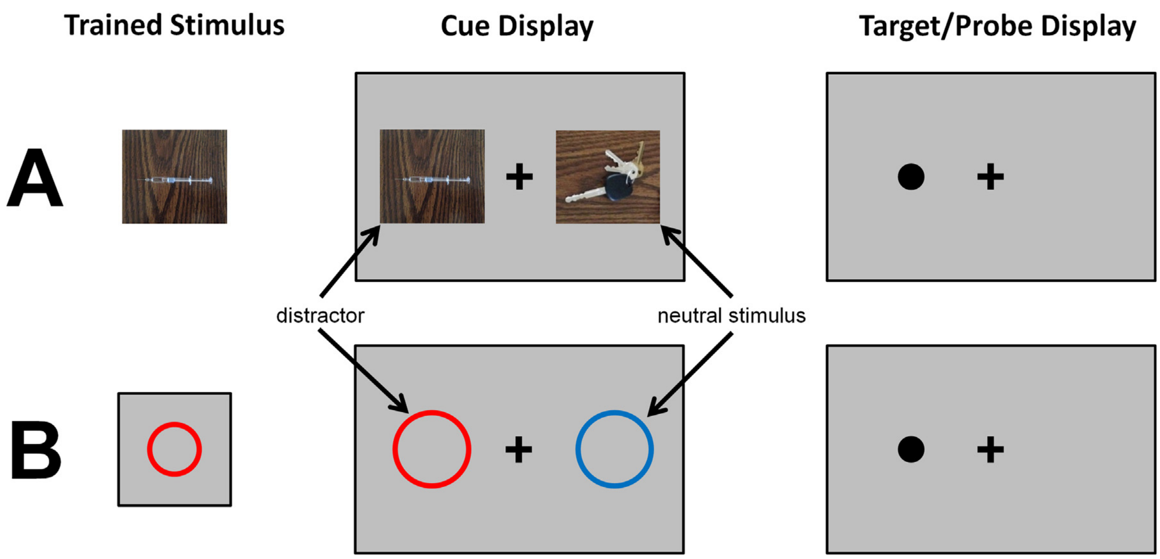

Fig. 1. Sample comparison of attentional biases for drug cues and arbitrary reward cues. For drug cues (A), the "training" involves real-life drug use in situations where the cue is present. For arbitrary reward cues (B), the cue is used to predict a reward outcome (often monetary gains) in the context of a laboratory experiment. When presented alongside a neutral stimulus after training, both cue types (now called distractors because they are explicitly task-irrelevant) facilitate processing of a target or probe appearing at their location after a brief delay (in this example, measured by the speed with which a probe dot is detected). These two forms of learned attentional bias share several important characteristics.

Table 1
Summary of key features that are common to attentional biases towards drug stimuli in addicted populations and attentional biases towards arbitrary reward cues in healthy participants.

Features of Attentional Bias	Arbitrary Reward Cues	Drug Cues
Resistant to conflicting goals	√	√
Endure long after learning	√	√
Overlapping neural mechanisms	√	√
Biases approach behavior	√	√
More prominent in drug- dependent populations	√	√

ened attentional priority. This has been referred to as *value-driven attentional capture* (Anderson, 2013).

Research on the value-driven control of attention has progressed more or less independently of research on addiction-related attentional bias, and there is currently very little cross-talk between the respective literatures. In this review, I will make the case that these two literatures are measuring the same cognitive process, that addiction-related attentional biases are a particular example of value-driven attention, providing a fruitful opportunity for translating findings from one literature to the other. Such a correspondence is not immediately obvious, as addiction-related attentional biases possess several striking characteristics that are not typically observed in normal cognition and can appear distinctly pathological. However, these same features can be observed in healthy individuals in the context of a psychology experiment (see Table 1). In short, following a few hundred trials of an associative learning task, any person can exhibit some of the most salient attentional characteristics of a drug-dependent individual. In the sections that follow, I outline five criteria that capture some of the key characteristics of addiction-related attentional biases, and describe how value-driven attention fulfills each of these criteria.

2.1. *Criterion 1: automatic and resistant to conflicting goals*

If the goal is to draw an analogy with addiction-related attentional biases, it is not enough to argue that reward history can also bias attention to non-drug stimuli. Addiction-related attentional biases occur when the drug cues are completely irrelevant to the task and in a context in which participants have the goal of attending to a different stimulus (Carpenter et al., 2006; Field and Cox, 2008; Field et al., 2004a,b, 2013; Marhe et al., 2013; Lubman et al., 2000; Marissen et al., 2006; Mogg et al., 2003; Stormark et al., 1997; Townshend and Duka, 2001), and under conditions in which the participant desires abstinence (Carpenter et al., 2006; Cox et al., 2002; Field et al., 2013; Marhe et al., 2013; Marissen et al., 2006; Waters et al., 2003b). This striking failure of current goals to overcome the bias to attend to drug cues attests to the powerful automaticity of this bias and helps to explain why sustaining desired abstinence can be so difficult (Berridge, 2012; Berridge and Robinson, 1998; Carpenter et al., 2006; Marissen et al., 2006; Robinson and Berridge, 1993).

It turns out that arbitrary stimuli, when previously associated with non-drug reward, can similarly capture attention in spite of conflicting goals. Even under conditions in which participants are aware that previously rewarded stimuli are irrelevant to the current task and should be ignored, and even when they are no longer expecting to receive any explicit rewards, these distractors capture attention and impair performance (e.g., Anderson et al., 2011a,b, 2014). Perhaps the most striking example of this can be found in a study in which participants were rewarded for identifying red and green targets during a training phase, and then completed a test phase in which they searched for a shape-defined target. On a subset of trials during the test phase, one of the non-targets was rendered in a previously reward-associated color from training. Color was completely irrelevant to the task and participants were informed of this, and no monetary rewards were available. The previously reward-associated non-targets (distractors) were only distinguishable on the basis of their particular color, apart from which there was nothing attention-grabbing about these stimuli. In spite of these conditions, search performance was impaired by the previously reward-associated distractors (Anderson et al., 2011b) and the distractors were fixated much more frequently than other non-targets (Anderson and Yantis, 2012). Thus, the reward learning had imbued these stimuli with an attention-capturing quality they did not have before, causing them to overpower goal-directed attentional selection.

The failure to ignore previously reward-associated stimuli even when completely irrelevant to the current task is now a well-