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Going for It: The Economics of Automaticity in Perception and Action

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Abstract
What we pay attention to is influenced by reward learning. Previously reward-associated stimuli are difficult to ignore, automatically drawing our attention even when we know they are no longer beneficial to us. Recent research has suggested that these value-dependent attentional biases affect more than just perception, biasing an individual to act in such a way as to pursue the attended stimulus. Here, I review this evidence and argue for a direct link between attentional biases and shifts in action-related priorities. Given this link, abnormal or otherwise inappropriate reward-related attentional biases are hypothesized to contribute to undesired habits and poor economic choices.

Keywords
selective attention, reward, distraction, decision making, automaticity

We live in the information age. A simple click on a webpage and we are immediately bombarded with information. We consume more media simultaneously than ever before, in the form of television, music, the Internet, video games, audiobooks, and more (Rideout, Foehr, & Roberts, 2010). Under these increasingly prevalent conditions, how we selectively process information is a critical determinant of our perceptual experience. We can process only a relatively small amount of information to a meaningful degree at any one moment in time, requiring us to "tune" our brains into a particular source of input, similar to how one needs to tune a radio to pick up different stations. This mental process of information selection defines the core feature of attention.

The Influence of Reward Learning on Attention

Although we may feel as though we can choose what we pay attention to based on our goals and intentions, certain stimuli have a tendency to draw our attention automatically. We may want to listen in on a conversation partner at a party yet find the contents of the television program playing in the background extremely distracting. What is distracting to us, and how distracting we find it, is not simply a function of the intensity of the raw stimulus input (e.g., how loud the television is, in this example) but is strongly affected by our learning history. When we have been rewarded in the past for paying attention to particular objects, these rewarded objects come to automatically draw our attention (Anderson, Laurent, & Yantis, 2011). The rewards can come in the form of explicit gains such as money (Anderson et al., 2011) and food (Pool, Brosch, Delplanque, & Sander, 2014), but they also include more subtle rewards such as positive social feedback from peers (Anderson, 2016). We are constantly learning which objects are more predictive of such rewarding outcomes than others, and this learning shapes our perceptual experience in future situations, biasing us to pay attention to what our past would suggest is likely to lead to positive consequences.

One of the most striking things about these reward-related attentional biases is their ability to overpower current intentions. Previously rewarded objects draw our attention even when we know they will only distract us from what really matters in a particular context (Anderson et al., 2011). One of the most compelling examples of this can be found in the case of addiction. Visual objects associated with a drug of abuse (e.g., a syringe in the case of an injectable drug or a pipe in the case of a smoked drug) automatically draw the attention of drug-dependent people, even when those people understand that drug abuse is harmful to them and desire abstinence (see Field

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& Cox, 2008, for a review). The intention to avoid the drug reward is not sufficient to suppress the tendency for attention to be pulled in by opportunities for drug use.

Reward-Related Attentional Biases in a Broader Context

The case of addiction raises a broader and important issue concerning the relationship between attentional biases and behavior. If attention is automatically drawn to a stimulus, but this has no effect on decision making, then the attentional bias will be of limited consequence. We may find the previously rewarded stimulus distracting, but this distraction will not lead us toward behaviors that we will later regret. Alternatively, reward-related attentional biases might have a cascading effect on information processing that ultimately biases behavior, causing us to be more likely to engage in reward-seeking behaviors directed toward the attention-grabbing stimulus.

In the case of addiction, there is evidence supporting a relationship between attentional bias and behavior: Attentional biases toward drug cues have been shown to predict relapse (e.g., Carpenter, Schreiber, Church, & McDowell, 2006; Marissen et al., 2006) and facilitate craving (Field & Eastwood, 2005), although their clinical utility has not been established (Christiansen, Schoenmakers, & Field, 2015). The more attention is drawn to drug-related stimuli, the more inclined an individual seems to be toward drug use. The question then becomes whether this relationship between biased attention and behavior is specific to addictions or reflects a broader principle that encompasses a range of human behavior. Recent research has demonstrated a clear link between (non-drug) reward-related attention and behavioral processes, suggesting that we are biased to pursue that which we cannot ignore.

Evidence Linking Reward-Related Attentional Biases to Decision Making and Action

Value-driven attention and economic choices

When attention is drawn to irrelevant but previously reward-predictive information, one consequence of this distraction might be that fewer processing resources are available to weigh different options and arrive at optimal decisions. Recent research by Itthipuripat, Cha, Rangsipat, and Serences (2015) confirmed this. When choosing between two options with different average payouts, participants made fewer optimal decisions when a previously high-value but currently task-irrelevant stimulus drew their attention. The more attention is diverted to previously reward-predictive information, the less consideration is given to concurrent economic decisions, thereby negatively impacting the quality of these decisions.

It is well documented that the value signals evoked by two competing stimuli and the likelihood of choosing the item of highest value are influenced by the value of a third, less desirable option (e.g., Louie, Grattan, & Glimcher, 2011; Louie, Khaw, & Glimcher, 2013). This phenomenon has been described in terms of *divisive normalization:* Rather than the values of individual items being represented in an absolute sense, value representations are normalized to the total reward available in a particular context (Louie et al., 2011; Louie et al., 2013; Rangel & Clithero, 2012). In this way, the greater the value associated with a less desirable option, the smaller the difference in relative value between the two higher-value options will be.

Interestingly, the experimental task used to assess the impact of value-driven attention on decision making (Itthipuripat et al., 2015) and the experimental tasks commonly used to study divisive normalization (Louie et al., 2011; Louie et al., 2013) are strikingly similar, differing primarily in the task relevance of a critical third stimulus (i.e., whether it represents a valid choice; see Fig. 1). Under the assumption that differential attention across stimuli is biased by their relative value (e.g., Navalpakkam, Koch, Rangel, & Perona, 2010), the amount of attention directed to differently valued alternatives may contribute to phenomena that have been attributed to divisive normalization. That is, the more processing resources are diverted to a particular stimulus (regardless of whether the participant considers it a viable option in the current context), the less robustly competing stimuli will be represented, interfering with the ability to distinguish between differently valued alternatives.

Another factor in economic decisions concerns the risk associated with a potential action. The risk an individual is willing to undertake is related to how much gain the individual believes to be at stake in a particular situation. Attentional processing of a reward-associated stimulus has also been shown to bias the perception of available reward, leading to riskier reward-seeking behavior. The more a reward-predictive stimulus draws the attention of an individual, the more the individual is willing to risk when making a gamble (San Martin, Appelbaum, Huettel, & Woldorff, 2016).

Fittingly, the degree to which previously reward-associated stimuli draw attention is correlated with individual differences in the reward-drive component of the behavioral activation system (Hickey, Chelazzi, & Theeuwes, 2010; Qi, Zeng, Ding, & Li, 2013). The reward-drive component of the behavioral activation system reflects the degree to which reward motivates behavior (Carver & White, 1994). This fits with the idea that the more reward-associated stimuli draw attention, the more behavioral

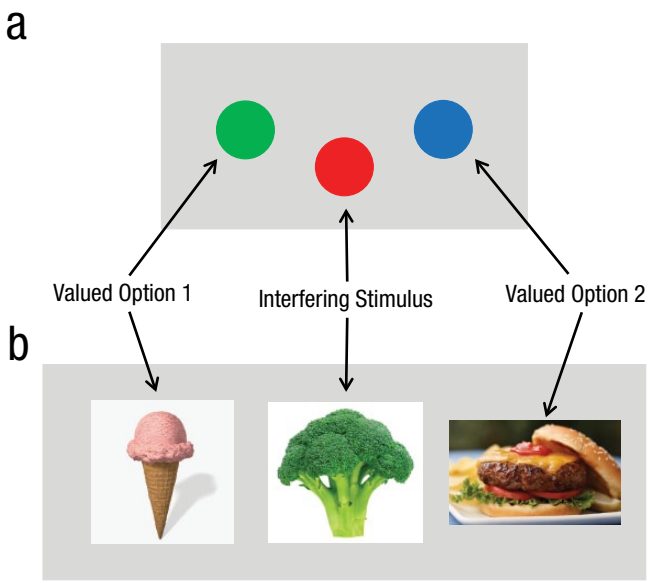

Fig. 1. Example stimuli from experimental tasks used to examine the impact of value-driven attention on decision making (Itthipuripat, Cha, Rangsipat, & Serences, 2015; a) and divisive normalization in decision making (Louie, Khaw, & Glimcher, 2013; b). In the first task (a), participants choose between two peripherally presented color stimuli associated with different average payouts (Valued Options 1 and 2) while trying to ignore the centrally presented stimulus (which cannot be selected). In the second task (b), participants choose which of the three items they want most, and these choices are compared against individual value ratings provided at the beginning of the experiment. In each case, the probability of choosing optimally between two differently valued options is negatively impacted by the value associated with a third (interfering) stimulus, even though this stimulus is not considered a viable option—either because it is not available for selection in the current context, as in panel (a), or because it is of lesser value than the two main alternatives, as in panel (b).

decisions will be influenced by the prospect of obtaining reward.

Value-driven attention and the activation of corresponding motor plans

Attention to reward-related stimuli also has more direct consequences for action selection. When a reward-associated stimulus calls for a particular response, the execution of this response is more robust to interference from competing action plans than are actions directed toward stimuli of lesser value (Krebs, Boehler, Egner, & Woldorff, 2011; Krebs, Boehler, & Woldorff, 2010). Essentially, when perception is more dominated by a particular stimulus based on its reward history, the action plan generated by that stimulus also receives elevated priority and more readily dominates response-selection processes.

Such preferential processing of action-related information is not limited to situations in which the stimulus is currently rewarded. When a previously reward-associated stimulus is associated with a motor response, the corresponding motor response plan is automatically triggered by the stimulus (Anderson, Laurent, & Yantis, 2012; Krebs et al., 2011; Krebs et al., 2010; see also Muhle-Karbe & Krebs, 2012). This automatic response activation can be observed even when the previously reward-associated stimulus is known to be completely task irrelevant and the individual has no intention of acting toward it (Anderson et al., 2012). A stimulus will exert an influence on the process of response selection if it is attended, regardless of whether the individual actually has the intention of attending to it or acting toward it.

Attention to a reward-associated stimulus also has a more general facilitative consequence for approach-oriented behavior, which is especially evident when individuals try to move past the stimulus. When a previously reward-predictive stimulus serves as an irrelevant distractor in a reaching task, the stimulus will bias the direction of body movements (Moher, Anderson, & Song, 2015). Specifically, reaches toward a target are more strongly diverted by previously reward-associated distractors than by other non-targets, requiring compensatory behavior in response to an enhanced pull on spatially guided action. Generally speaking, approach behavior is biased toward the stimuli that we pay attention to, even when this attention comes in the form of involuntary distraction.

Parallel evidence for this idea has been found in studies examining the influence of reward cues on motor-cortex excitability. The presentation of a reward cue is associated with a rapid increase in motor activity, even when participants are required to withhold from responding (Freeman & Aron, 2015). This reward-mediated response activation creates greater demands on inhibitory processes in order to successfully withhold the response (Freeman & Aron, 2015; Freeman, Razhas, & Aron, 2014), which requires effortful cognitive control that is subject to fatigue (Freeman & Aron, 2015).

Value-driven attention and disinhibition

Another way that attention to reward-related stimuli influences behavior is through disinhibition. Normally, when a stimulus signals the need to withhold a response (a *no-go* stimulus), individuals inhibit the behavior associated with that stimulus. Experimentally, this inhibition makes it harder to execute the inhibited response when a subsequent target stimulus requires that response, resulting in a reverse compatibility effect (Anderson & Folk, 2012, 2014; Anderson, Folk, & Courtney, 2016). When the no-go stimulus is presented in a color previously associated with reward, however, the pattern completely reverses: The response associated with the no-go stimulus is activated

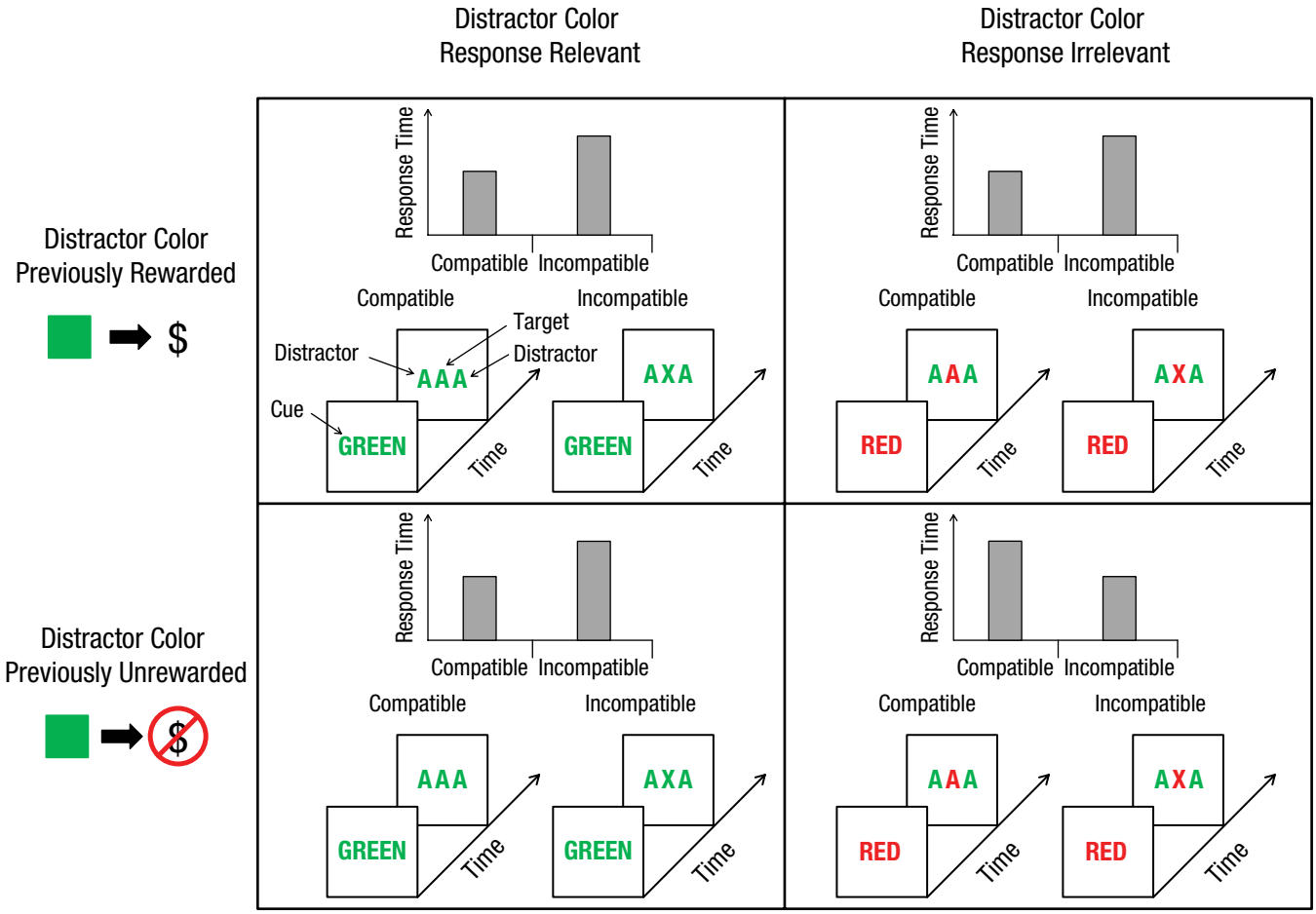

Fig. 2. Schematic of the relationship among reward history, intentions, and the effect of task-irrelevant stimuli (distractors) on response selection. In the experimental task depicted, participants respond to the target (center letter) only if its color matches that of a cue at the beginning of each trial, pressing one key for *A* and another key for *X*. Task-irrelevant distractors flank the target and can be presented in either the response-relevant (cued) or response-irrelevant (uncued) color. The effect of the distractors on response selection is measured as a *compatibility effect:* Faster responses on compatible trials (same response association as the target) relative to incompatible trials (different response association) indicate activation of the distractor-associated response, whereas the opposite pattern indicates inhibition of the distractor-associated response. When the color of the distractors was not previously associated with reward during training, a strong modulation of the compatibility effect by response relevance is observed (compare the panels in the bottom row), whereas no such modulation is observed when the color of the distractors was previously associated with reward (compare the panels in the top row). That is, when the distractors were not previously associated with reward, participants inhibited their corresponding response when their color was not response relevant (lower-right panel); participants were unable to do so when the distractors were presented in a previously reward-associated color (upper-right panel), responding as if the color was in fact response relevant (left two panels). Adapted from "Mechanisms of Habitual Approach: Failure to Suppress Irrelevant Responses Evoked by Previously Reward-Associated Stimuli," by B. A. Anderson, C. L. Folk, R. Garrison, and L. Rogers, 2016, *Journal of Experimental Psychology: General, 145*, p. 799. Copyright 2016 by the American Psychological Association. Adapted with permission.

rather than inhibited, resulting in a typical response-compatibility effect (Anderson, Folk, Garrison, & Rogers, 2016). Previously reward-associated stimuli escape inhibitory processes, such that the response associated with such stimuli facilitates action regardless of whether the individual has the intention of inhibiting that action (see Fig. 2).

Value-driven attention and psychopathology

Finally, if attention to reward-related stimuli influences behavior, we might hypothesize that abnormal attention to such stimuli would be associated with abnormal reward-related behaviors. Recent research has supported this hypothesis, suggesting that both abnormally strong and abnormally weak reward-related attentional biases are linked to corresponding psychopathology. Individuals in treatment for drug addiction are more distracted by stimuli previously associated with (non-drug) reward than are control participants (Anderson, Faulkner, Rilee, Yantis, & Marvel, 2013), as are individuals who have a history of struggling with addiction but are currently drug-free (Anderson, Kronemer, Rilee, Sacktor, & Marvel, 2016). The strength with which a reward-associated stimulus draws attention is also associated with the degree of

one's tendency toward impulsive non-planning behaviors, including those related to HIV risk (Anderson, Kronemer, et al., 2016). On the other end of the spectrum, individuals who struggle with depressive systems show markedly blunted attentional biases toward reward-associated stimuli (Anderson, Leal, Hall, Yassa, & Yantis, 2014). The more depressed an individual is, the less his or her attention is influenced by reward history.

Conclusions

Attention is automatically drawn to stimuli that have predicted rewarding outcomes in our past, even when we want to ignore them. Not only can this be distracting, but it also has consequences for the decisions we make and the actions we take. When attention is drawn to a previously reward-associated stimulus, the corresponding shift in information processing biases us to act in such a way as to pursue the attended stimulus. When the attention-grabbing stimulus is consistent with our current goals and desires, this can facilitate good decisions that lead to reward. However, when the attention-grabbing stimulus is not desirable in a particular context, this bias could lead to inappropriate behaviors and suboptimal decisions.

The evidence presented here links value-driven attention to fundamental mechanisms of behavior. Using targeted experimental measures, it is possible to observe biases in decision making and approach-oriented action toward task-irrelevant but previously reward-associated stimuli. Precisely how these biases translate to complex real-world behavior outside of a controlled experimental setting is unclear and reflects an exciting future research direction. To the degree that the lower-level information-processing biases discussed in this article shift the probability of choosing to pursue a particular opportunity or settling upon a particular course of action from among multiple competing alternatives, meaningful consequences for higher-level behavioral outcomes might be expected.

Recommended Reading

Anderson, B. A. (2016a). The attention habit: How reward learning shapes attentional selection. *Annals of the New York Academy of Sciences*, *1369*, 24–39. A comprehensive and up-to-date review of how reward learning influences attention.

Anderson, B. A. (2016b). What is abnormal about addiction-related attentional biases? *Drug and Alcohol Dependence*, *167*, 8–14. A thorough and user-friendly review of the relationship between reward-related attention and addictive behaviors.

Anderson, B. A., Folk, C. L., Garrison, R., & Rogers, L. (2016). (See References). An unambiguous demonstration of how reward-related attention can influence response selection.

Itthipuripat, S., Cha, K., Rangsipat, N., & Serences, J. T. (2015). (See References). An elegant demonstration of how distraction by reward-related stimuli impairs value-based decision making.

Declaration of Conflicting Interests

The author declared no conflicts of interest with respect to the authorship or the publication of this article.

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