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Health Psychology
2016, Vol. 35, No. 8, 767–780

0278-6133/16/$12.00 http://dx.doi.org/10.1037/hea0000405

The Role of Attentional Bias in Obesity and Addiction

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Objectives: The purpose of this article is to critically evaluate the following claims derived from contemporary theoretical models of attentional bias (AB) for food- and drug-related stimuli: (a) AB is a characteristic feature of obesity and addiction, (b) AB predicts future behavior, (c) AB exerts a causal influence on consummatory behavior, and (d) AB reflects appetitive motivational processes. ***Method:*** A focused discussion of the relevant literature is presented. ***Results:*** The available evidence reveals inconsistencies with the aforementioned claims. Specifically, AB is not consistently associated with individual differences in body weight or drug use, AB does not consistently predict or influence distal consummatory behavior, and AB may be influenced by both appetitive and aversive motivational processes. These insights are synthesized into a theoretical account that claims that AB for food- and drug-related stimuli arises from momentary changes in evaluations of those stimuli that can be either positive (when the incentive value of the food or drug is high), negative (when individuals have a goal to change their behavior, and those stimuli are perceived as aversive), or both (when individuals experience motivational conflict, or ambivalence). ***Conclusions:*** The proposed theoretical synthesis may account for the contributions of appetitive and aversive motivational processes involved in self-regulatory conflicts to AB, and it yields testable predictions about the conditions under which AB should predict and have a causal influence on future consummatory behavior. This has implications for the prediction and modification of unhealthy behaviors and associated disorders.

Keywords: ambivalence, attentional bias, conflict, craving, evaluation

Individual differences in both appetitive and aversive motivation are associated with *attentional bias* (AB) for salient environmental cues. Regarding appetitive motivation, substance use disorders (addiction) and obesity, and subjective states of craving and hunger, are associated with AB for drug- and food-related stimuli, respectively (Field & Cox, 2008; Werthmann, Jansen, & Roefs, 2015). Regarding aversive motivation, individuals with anxiety disorders, and people in an anxious state, have an AB for threatening stimuli in their environment (Cisler & Koster, 2010). This paper presents a critical discussion of the relationship between appetitive motivation and AB, with a focus on addiction and obesity.

First, an overview of theoretical models of AB is provided and their shared predictions are highlighted, namely (a) AB should be most pronounced in people who are addicted or obese, (b) AB predicts future behavior, (c) AB exerts a causal influence on behavior, and (d) AB reflects appetitive motivational processes. This is followed by a focused review of the relevant literature in which findings that that are compatible and incompatible with these predictions are discussed. A number of important observations are highlighted, including inconsistent cross-sectional and prospective associations between AB and individual differences in body weight and drug use, unconvincing evidence for a causal influence of AB on behavior, and demonstrations that both appetitive and aversive motivational processes appear to influence AB.

In the final part of the paper, we synthesize these observations and propose a novel account of AB in obesity and addiction. The central claims of this account are that (a) AB is primarily determined by current evaluations of drug-and food-related cues, and those evaluations can be positive or negative, or both simultane-

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ously (ambivalence), (b) the stability and predictive validity of AB and its causal influence on behavior have been overstated, and (c) the sensitivity of AB to the current motivational state and conflicting goals have been underappreciated.

Definition and Measurement of Attentional Bias

AB can be defined as the tendency for specific types of stimuli (here, drug- and food-related pictures and words, hereafter referred to as "substance cues") to capture and/or hold the attention. Detailed descriptions of AB methods and their limitations are available elsewhere (Field & Cox, 2008; Field & Franken, 2014; Nijs & Franken, 2012; Werthmann, Jansen et al., 2015; Yiend, 2010), and a brief description of the most commonly used methods is provided here.

In the modified Stroop task, words are presented in different colors and participants are required to identify the color of the words while ignoring their meaning. If participants are slower to identify the color of one category of words (e.g., food-related words) than another (e.g., office-related words), the inference is that the former category of words captured the attention and interfered with color naming.

In the visual probe task (and other types of attentional cueing tasks), a pair of words or pictures is briefly presented on a computer screen before a visual "probe" (e.g., a small arrow) appears in the location that had been occupied by one of the stimuli. Participants are instructed to respond to the probe as rapidly as possible, and if reaction times (RTs) are consistently faster to probes that replace one type of stimulus (e.g., pictures of cigarettes) compared to another (e.g., pictures of pencils), the inference is that participants' attention was directed at the former objects just before the probe appeared (Yiend, 2010). An appealing feature of the task is that, unlike the Stroop task, RTs from the visual probe task can distinguish between AB for a certain category of stimuli (e.g., smoking-related pictures) and attentional avoidance of those stimuli; that is a bias to direct attention away from those stimuli rather than toward them. Attentional avoidance, which can be thought of as a special type of AB, is inferred if participants are faster to respond to probes that replace control stimuli rather than probes that replace substance-related stimuli (Yiend, 2010).

Finally, electroencephalography (EEG) can be used to measure attentional processing of motivationally salient stimuli. In a typical task, images are individually presented on a computer screen for several seconds while scalp-mounted electrodes record event-related potentials (ERPs) that are evoked by the stimuli. Some components of the ERP, in particular the P300 and the slow potential, are associated with allocation of attention to those stimuli ("motivated attention"; Schupp et al., 2004). Therefore their amplitude in response to motivationally salient versus control pictures is interpreted as a marker of AB (Littel, Euser, Munafò, & Franken, 2012).

There are methodological issues with all of these measures. First, both the modified Stroop task and ERPs yield outcome measures that are difficult to interpret: Identical patterns of Stroop interference are produced by appetitive and aversive words, and therefore any observed AB in the task may arise because words are evaluated positively or negatively, or both (Yiend, 2010). Similarly, the P300 and slow potential components of the ERP cannot distinguish between appetitive and aversive responses to the stimuli (Briggs & Martin, 2009; Little et al., 2012; Polich, 2007). Second, each of these tasks can be influenced by cognitive strategies that participants might employ in an attempt to suppress AB (Yiend, 2010; Littel & Franken, 2011; Meule, Kübler, & Blechert, 2013). Finally, RT indices of AB derived from the modified Stroop and visual probe tasks are limited by poor internal reliability (Ataya et al., 2012; Van Bockstaele et al., 2014). Fortunately, more reliable (and direct) indices of AB may be obtained by monitoring participants' eye movements as they complete the visual probe task (Christiansen, Mansfield, Duckworth, Field, & Jones, 2015).

Existing Theoretical Models of AB and Their Predictions

This section provides a brief overview of theories of addiction and obesity that posit a role for AB for substance cues, and highlights predictions that are shared by these theories. The discussion is limited to theories that have provided the impetus for research on AB in addiction and obesity, but other relevant theories are discussed later in the paper. Arguably most influential is the *incentive-sensitization* theory (IST) of drug addiction proposed by Robinson and Berridge (1993). The central tenet of this theory is that consumption of drugs increases dopamine transmission in reward-related regions of the brain (specifically, the nucleus accumbens and other structures that form the mesolimbic dopamine system), and this dopamine response becomes sensitized (it progressively increases) with each episode of drug consumption. The resulting sensitized dopamine activity in the reward system increases the motivational appeal of the drug, and the subjective corollary of this is subjective craving. Through an associative learning process, drug-related cues acquire strong motivational properties (incentive salience) and as a consequence those cues "grab attention, become attractive and wanted, and thus guide behavior to the incentive" (Robinson & Berridge, 1993, p. 261).

The IST was originally proposed to account for dopamine adaptations in response to addictive drugs and in its original formulation, sensitization processes were proposed to occur only for addictive drugs but not for other, "natural" rewards such as food. However, subsequent work on the nature of brain adaptations in obesity, including by one of the original proponents of IST (Berridge, 2009) prompted the development of theories that propose that identical processes occur as a consequence of repeated consumption of food. For example, Nijs and Franken (2012) stated that

> neurocognitive addiction models, such as the (IST) might be applicable to obesity. This means that, similar to addiction, an attention bias to rewarding foods might play an important role in the development and maintenance of overeating behavior and weight gain/obesity. (p. 107; see also Volkow & Wise, 2005)

Similarly, a recent *temptation management* model of obesity treatment proposed *that* "for obese individuals participating in lifestyle interventions, palatable food may act as a 'motivational magnet' that monopolizes attention and triggers lapses in diet adherence" (Appelhans, French, Pagoto, & Sherwood, 2016, p. 270).

The term *craving* refers to a "drug acquisitive motivational state" (Baker, Morse, & Sherman, 1986, p. 258), which is synonymous with "desire", an "affectively charged motivation . . . the feeling of wanting to have or do something (that) motivates behavior" (Hofmann & Van Dillen, 2012, p. 317). The theories discussed above claim that subjective craving/desire should be closely associated with the magnitude of AB. This prediction was refined by subsequent theories, initially Franken's cognitive psychopharmacological model (Franken, 2003) and subsequently by the Elaborated Intrusion (EI; Kavanagh, Andrade, & May, 2005) and the Dynamical models (Hofmann & Van Dillen, 2012) of desire. These theories posit that craving and AB are both outputs of an underlying appetitive motivational process. Importantly, they diverge from earlier predictions (such as those made by IST) by claiming that, once activated, each can increase the strength of the other until a threshold is crossed, at which point the person "gives in to temptation" and consumes the substance.

Several predictions are common to each of these theories. First, AB for substance cues develops as a consequence of associative learning and once established, it should be a long-lasting characteristic. Therefore, AB for drug-related cues should be present in all drug users but most pronounced in those with more frequent exposure to the drug, that is, heavy users with more severe addiction. Regarding AB for food stimuli, most people have experience of eating food, so AB for food should be present in almost everybody to some degree (Werthmann, Roefs, Nederkoorn, Mogg et al., 2013). However, given that obesity is primarily attributable to overeating (Cecil et al., 2012), AB for food stimuli should be most pronounced in people who are obese (see Nijs & Franken, 2012 and Appelhans et al., 2016, who make this claim explicitly).

The second shared prediction is that individual differences in AB should predict future behavior, in particular the probability of seeking out and consuming that substance, the amount consumed, or the likelihood of relapse to drug use, or weight gain (due to increased food intake) after treatment. The third shared prediction is that, in addition to being predictive, AB has a *causal influence* on consummatory behavior (i.e., eating and drug use). The fourth and final shared prediction is that AB reflects an underlying appetitive motivational process, and therefore it should be strongly correlated with subjective craving or desire for the substance.

In the following sections of this paper, each of these predictions is critically evaluated. The evidence base is large, and it is beyond the scope of the present paper to provide an exhaustive review (for comprehensive reviews of this literature, see Doolan, Breslin, Hanna, & Gallagher, 2014; Field & Cox, 2008; Leeman, Robinson, Waters, & Sofuoglu, 2014; Nijs & Franken, 2012; Werthmann, Jansen et al., 2015).

Prediction 1: Is AB Stronger in People Who Are Addicted or Obese, Compared to Those Who Are Not?

This prediction can be evaluated with reference to reviews and meta-analyses of studies that reported between-groups comparisons in AB between addicted or obese samples and controls. First, regarding AB for drug-related cues, meta-analyses have confirmed that AB for drug-related cues (including alcohol and tobacco cues) is larger in users versus nonusers of those drugs (e.g., smokers vs. nonsmokers) when the modified Stroop task (Cox, Fadardi, & Pothos, 2006) and ERP measures (Littel et al., 2012) are used to measure AB. Regarding the visual probe task, narrative reviews of studies that used this and related tasks (Field & Cox, 2008; Field, Marhe, & Franken, 2014), sometimes in combination with eye movement monitoring, confirmed the presence of AB in users versus nonusers of those drugs. However, within addict groups, the associations between AB and individual differences in the quantity or frequency of tobacco smoking and alcohol consumption are inconsistent (Field & Cox, 2008). For example, on the visual probe task, some studies report that AB is stronger in heavy (more frequent) smokers, whereas others report the opposite (e.g., Mogg, Field, & Bradley, 2005; Vollstadt-Klein et al., 2011). Other studies that used the task demonstrated attentional avoidance or an "approach–avoidance" (ambivalent) pattern of AB in alcohol-dependent patients who were undergoing treatment, relative to nondependent controls: initial orienting of attention toward alcohol stimuli followed by the shifting of attention away from those stimuli (reviewed in Field, Mogg, Mann, Bennett, & Bradley, 2013).

Narrative reviews of the literature on food-related AB in obese and normal-weight participants concluded that findings have been very inconsistent, in the sense that the nature of group differences varied across studies. For example, Werthmann, Jansen et al. (2015) noted that of 11 published studies, some reported that AB was positively associated with obesity and overweight, others reported the opposite (smaller AB in overweight and obese participants), and others reported no difference (see also Doolan et al., 2014; Nijs & Franken, 2012). An observation may clarify the relationship between AB and obesity: if participants were tested in a hungry state this tended to mask between-groups differences, but AB was larger in obese compared to normal weight participants if participants were sated at the time of testing (Castellanos et al., 2009; Nijs, Muris, Euser, & Franken, 2010). One explanation is that ceiling effects in AB when people are hungry may mask between-groups differences, an issue that is revisited later in this paper.

In summary, the addiction literature is partly consistent with theoretical predictions because AB for drug cues is larger in drug users versus nonusers, and this effect is robust. However, contrary to theoretical predictions, AB is not consistently stronger in people who are more dependent or use the drug more frequently. The obesity literature does not offer strong support to theoretical predictions because cross-sectional studies suggest that obesity is not robustly associated with elevated AB for food-related cues.

Prediction 2: Is the Strength of AB a Good Predictor of Future Behavior, Specifically Drug Use and Food Intake, or the Consequences of That Behavior, Such as Changes in Body Weight?

Several studies demonstrated that individual differences in AB were positively correlated with individual differences in ad libitum food consumption that was measured immediately after assessment of AB (Nijs, Muris, et al., 2010; Werthmann, Renner et al., 2014; Werthmann, Roefs, Nederkoorn, & Jansen, 2013; but see Hardman, Scott, Field, & Jones, 2014). Two other studies investigated the association between AB for food and subsequent change in body weight and reported the predicted associations, although the findings were not robust because in both studies, only some measures of AB were predictive of body weight at some, but not all, follow-up assessments (Calitri, Pothos, Tapper, Brunstrom, & Rogers, 2010; Werthmann et al., 2015). Regarding addiction studies, the evidence for predictive validity of AB is very inconsistent. Christiansen, Schoenmakers, and Field (2015) reviewed 15 prospective studies, the majority of which measured AB in clinical settings in patients who were receiving treatment at the time. Overall, there was no consistent prospective relationship between AB measured in clinical settings and relapse to drug use that occurred days, weeks or months later. Finally, two studies demonstrated that behavioral measures of AB were not predictive of future behavior, but patterns of brain activation during AB were predictive (Marhe, Waters, Van De Wetering, & Franken, 2013; Yokum, Ng, & Stice, 2011). These dissociations are intriguing, and further research is required to determine if they can be attributed to the relatively poor reliability of behavioral measures (Ataya et al., 2012; Van Bockstaele et al., 2014), or if patterns of brain activation associated with AB capture something qualitatively different to behavioral measures.

Overall, it appears that the predictive relationship between AB and future behavior is not robust, particularly when there is a long time interval between assessment of AB and changes in drug use or body weight. However, findings from a recent study (Marhe et al., 2013) suggest that AB might predict behavior in the very near future. In this study, heroin-dependent patients who were undergoing detoxification completed a Stroop task on a mobile electronic device several times per day for 1 week. Analyses revealed that, in participants who relapsed during the study week, AB was particularly high just before relapse occurred. If this finding could be replicated and extended, the implication would be that AB has a particularly close relationship with increased risk of relapse in the very near future, but its predictive validity is reduced as the delay between assessment of AB and the occurrence of relapse lengthens.

In summary, prospective studies suggest that there is no consistent relationship between AB and distal behavior, but AB may predict behavior that occurs in the near future. This is problematic for theoretical models that frame AB as an enduring "trait" characteristic that can predict a person's behavior in the distant future. One explanation for this pattern of findings is that motivational state fluctuates over time, which means that there is likely to be a mismatch between a person's motivational state when AB is assessed (typically in the lab or clinic), and their motivational state when they actually consume the substance outside of the lab or clinic, which could be several hours, weeks, or months later.

Prediction 3: Does AB Have a Causal Influence on Behavior and Subjective Craving?

This prediction can be evaluated with reference to attentional bias modification (ABM) studies, in which AB is directly manipulated before subjective motivational states and behavior are assessed. These studies serve two purposes. First, they enable testing of theoretical predictions that increases in AB should influence motivational state and the consumption of drugs and food. Second, they represent a translational application of AB research, because ABM may prompt reductions in subjective craving and substance consumption. The majority of ABM studies used a modified visual probe task (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002) in which the location of visual probes was systematically varied so that participants were trained to either attend toward ("attend substance" groups) or away from ("avoid substance" groups) a specific category of stimuli (e.g., food pictures), but AB was not manipulated in control groups.

ABM studies conducted with drug users were reviewed by Christiansen et al. (2015). Several studies investigated the effects of a single session of ABM for alcohol cues (three studies), smoking cues (three studies), or opiate cues (one study) on subjective craving and/or substance use. Some of these reported that ABM may have a causal influence on craving, because participants in attend substance groups reported increased alcohol craving (Field, Duka et al., 2007; Field & Eastwood, 2005) or cigarette craving (Attwood, O'Sullivan, Leonards, Mackintosh, & Munafò, 2008) after ABM, although these effects were limited to subgroups of participants in the later studies (Attwood et al., 2008; Field, Duka et al., 2007). Unfortunately, none of the studies that contrasted avoid substance with control conditions reported a reduction in craving after ABM (Attwood et al., 2008; Charles et al., 2015; Field, Duka et al., 2007; Field & Eastwood, 2005; McHugh, Murray, Hearon, Calkins, & Otto, 2010; Schoenmakers, Wiers, Jones, Bruce, & Jansen, 2007). Of these seven studies, only one reported the predicted effects of ABM on consummatory behavior (Field & Eastwood, 2005); this was not replicated in the other studies.

Subsequent studies investigated the effects of multiple sessions of ABM in patients who were trying to abstain from alcohol or tobacco. Two studies administered ABM in clinical settings to tobacco smokers, and both reported no effect on craving or relapse to smoking (Begh et al., 2015; Lopes, Pires, & Bizarro, 2014). Findings from trials of ABM with problem drinkers are difficult to interpret given lack of an active control condition in two studies (Cox, Fadardi, Hosier & Pothos, 2015; Fadardi & Cox, 2009; see Wiers et al., 2015) and low statistical power and ambiguous findings in another (Schoenmakers et al., 2010).

More encouraging results were reported by McGeary, Meadows, Amir, and Gibb (2014). In their study, heavy drinking students who completed 4 weeks of avoid-alcohol ABM in their own homes reported drinking alcohol less frequently, compared to a control group. In another study (Kerst & Waters, 2014), tobacco smokers (who were not attempting to quit) completed 15 sessions of ABM on a mobile device, together with craving measures, over 1 week. Compared to a control group, participants in the avoid-smoking group showed a reduction in AB and a corresponding reduction in subjective craving over the course of the week.

Werthmann, Jansen et al. (2015) reviewed studies that investigated the effects of ABM for food-related cues. The majority of studies measured participants' food intake after single sessions of attend-food or avoid-food manipulations, and most found the predicted effects: higher consumption of foods corresponding to pictures that were trained in the attend compared to the avoid groups (Kakoschke, Kemps, & Tiggemann, 2014; Kemps, Tiggemann, & Elford, 2015; Kemps, Tiggemann, Orr, & Grear, 2014; Werthmann, Field, Roefs, Nederkoorn, & Jansen, 2014). Although these findings are promising, interpretation is complicated because most studies contrasted the effects of attend-food and avoid food manipulations but did not include a control group, so it is unclear if the attend food ABM manipulation led to increased food intake, if the avoid food ABM manipulation led to reduced food intake, or both. Furthermore, two studies reported no change in either AB or food intake after ABM (Boutelle, Kuckertz, Carlson, & Amir, 2014; Hardman, Rogers, Etchells, Houstoun, & Munafò, 2013).

In summary, the evidence is consistent with the claim that experimentally induced AB may prompt an increase in subjective craving and/or consummatory behavior, an interpretation that is consistent with the theoretical predictions outlined above. However, it is less clear if experimentally reduced AB leads to a reduction in craving or reduced consummatory behavior, particularly outside of the laboratory setting. Recent addiction studies suggest that multiple ABM sessions might prompt reductions in craving or changes in behavior, particularly if participants complete ABM on a computer at home, or on a mobile device as they go about their daily lives. Further studies are required to confirm these findings.

Prediction 4: Is AB Indicative of Underlying Appetitive Motivational Processes?

The final prediction shared by existing theories is that AB is indicative of underlying appetitive motivational processes, and therefore it should be positively correlated with the strength of subjective craving or hunger. The available evidence supports this prediction. A meta-analysis of addiction studies conducted in the laboratory reported a robust, albeit weak (r = .19) positive correlation between AB and craving (Field, Munafò, & Franken, 2009), and a recent experience sampling study confirmed that AB and drug craving tend to co-occur in naturalistic settings outside of the laboratory (Waters, Marhe, & Franken, 2012). Regarding AB for food-related cues, two recent narrative reviews (Doolan et al., 2014; Werthmann, Jansen et al., 2015) identified several studies that reported significant positive correlations between food-related AB and general hunger or food-specific craving in the laboratory (Castellanos et al., 2009; Gearhardt, Treat, Hollingworth, & Corbin, 2012; Graham, Hoover, Ceballos, & Komogortsev, 2011; Mogg, Bradley, Hyare, & Lee, 1998; Nijs, Franken, & Muris, 2010; Nijs, Muris et al., 2010; Schmitz, Naumann, Trentowska, & Svaldi, 2014; Tapper, Pothos, & Lawrence, 2010; Werthmann, Roefs, Nederkoorn, & Jansen, 2013; Werthmann et al., 2011) although this relationship was not observed in all studies (Hardman et al., 2014; Loeber, Grosshans, Herpertz, Kiefer, & Herpertz, 2013; Loeber et al., 2012; Nummenmaa, Hietanen, Calvo, & Hyönä, 2011).

Further evidence for an association between AB and subjective motivational states comes from studies that directly manipulated the motivational state before observing the effect on AB. As reviewed elsewhere (Field & Cox, 2008; Field & Franken, 2014), experimental manipulations such as alcohol administration, nicotine deprivation, negative mood induction and cue exposure led to increases in subjective craving that were accompanied by increases in AB (Bradley, Garner, Hudson, & Mogg, 2007; Field, Mogg, & Bradley, 2004, 2005; Field & Powell, 2007; Field & Quigley, 2009; Field, Rush, Cole, & Goudie, 2007; Grant, Stewart, & Birch, 2007; Ramirez, Monti, & Colwill, 2015a, 2015b; Schoenmakers, Wiers, & Field, 2008), although this was not seen in all studies (Eastwood, Bradley, Mogg, Tyler, & Field, 2010; Mogg & Bradley, 2002; Schoenmakers & Wiers, 2010). Other experimental manipulations that reduced subjective craving also suggest correspondence between AB and craving: reductions in subjective craving accompanied by reduced AB were seen after brief exercise (Oh & Taylor, 2013, 2014; Van Rensburg, Taylor, & Hodgson, 2009), devaluation of alcoholic drinks by making them taste unpleasant (Rose, Brown, Field, & Hogarth, 2013), and emotional reappraisal (Szasz, Szentagotai, & Hofmann, 2012).

With regards to AB for food, an early study demonstrated that subjective hunger and AB increased after a period of fasting (Lavy & Van den Hout, 1993). Subsequent experimental manipulations of fasting tended to confirm this finding (Castellanos et al., 2009; Channon & Hayward, 1990; Nijs, Muris et al., 2010; Piech, Pastorino, & Zald, 2010; Stockburger, Schmälzle, Flaisch, Bublatzky, & Schupp, 2009; Placanica, Faunce, & Soames Job, 2002), although not in all studies (Leland & Pineda, 2006; Mogg et al., 1998). Subjective hunger has also been manipulated (up or down) in other ways, and these studies suggest close correspondence between hunger and AB after exposure to chocolate cues (Smeets, Roefs, & Jansen, 2009), negative mood induction (Hepworth, Mogg, Brignell, & Bradley, 2010; although see Werthmann, Renner et al., 2014), and after exercise (Oh & Taylor, 2013, 2014).

In summary, there is compelling evidence that AB fluctuates alongside subjective craving or hunger, and that experimentally induced changes in these appetitive motivational states are accompanied by changes in AB. This evidence is consistent with theoretical predictions that AB reflects an appetitive motivational process. These studies also illustrate an important point that has been alluded to in previous sections: within-subject fluctuations in AB might be more important than between-groups differences. This could partly explain why differences in AB between users and nonusers of addictive drugs (e.g., heroin users vs. nonusers) appear robust, because, on average, subjective craving for heroin will be higher in users versus nonusers. However, within groups of people who regularly consume drugs (e.g., alcohol consumers) and food (i.e., everybody), AB may be closely associated with the current level of craving or hunger, respectively. This could obscure associations between AB measured in the laboratory and individual differences in substance consumption outside of the laboratory (, e.g., the number of alcoholic drinks or food calories consumed within a week), or the consequences of overconsumption such as obesity.

The Roles of Aversive Motivation and Motivational Conflict

The involvement of appetitive motivational processes in AB does not preclude the possibility that aversive motivational processes, and the conflict between appetitive and aversive motivational processes, might also be important. Both addiction (Miller, 1996) and obesity (Armstrong et al., 2011; Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2008) are characterized by motivational conflict (or ambivalence). Indeed, most people experience occasional conflict between enjoyment of food and the desire to maintain a healthy weight (De Ridder, Adriaanse, Evers, & Verhoeven, 2014), particularly those who are obese (Andreyeva, Long, Henderson, & Grode, 2010). Motivational conflict could be very important in the context of AB, because when a person feels conflicted about a substance, stimuli associated with that substance may be evaluated as attractive and aversive, because they are desired but they also represent a threat to the goal of behavior change (Cacioppo, Gardner, & Berntson, 1999). If this speculation is correct, one might expect to see very different patterns of AB for substance cues in people who experience motivational conflict about the substance versus, those who do not. Specifically, in people who experience motivational conflict, substance cues might be evaluated negatively and provoke concerns ("worry") about the problem behavior, and those people may also attempt to override their AB for substance-related cues in order to regulate their emotional response (Koole, 2009) or suppress subjective craving (Hofmann & Van Dillen, 2012). Indeed, research in other domains has demonstrated that momentary goals can bias attention toward stimuli that are relevant to those goals, even when those stimuli compete with other motivationally salient stimuli (Cox, Klinger & Fadardi, 2006; Vogt & De Houwer, 2014; Vogt, De Houwer, Crombez, & Van Damme, 2013), and some previous accounts claimed that both appetitive and aversive processes could contribute to AB in people who were attempting to control their behavior (Field & Cox, 2008; Lee & Shafran, 2004; Roefs, Houben, & Werthmann, 2015; Werthmann, Jansen et al., 2015).

Careful consideration of the role of motivational conflict may explain some apparent inconsistencies in the existing AB literature. Alcohol-dependent patients who have received (or are still receiving) hospital treatment and are attempting to remain abstinent exhibit a pattern of AB that is qualitatively different from that seen in heavy drinkers who are not attempting to abstain or reduce their drinking, and who are not usually tested in hospital settings. As reviewed elsewhere (Field et al., 2013), studies that used the visual probe task demonstrated that alcohol-dependent patients had an AB for alcohol cues if those cues were presented briefly, but this switched to attentional avoidance when pictures were presented for half a second or longer. One interpretation (see Field et al., 2013) is that this "approach–avoidance" pattern is associated with the motivational conflict that dependent patients experience during treatment. Direct support for the notion that an approach–avoidance pattern of AB is associated with motivational conflict is provided by a recent study (Lee, Cho, & Lee, 2014) in which problem drinkers with and without ambivalence (motivational conflict) viewed pairs of alcohol-related and matched neutral pictures while their eye movements were recorded. The conflicted drinkers tended to direct their gaze toward alcohol pictures at the beginning of each trial, but they directed their gaze away from the alcohol pictures at the end of the trial. Drinkers who were not conflicted about their drinking tended to maintain their gaze on alcohol pictures throughout each trial.

The observed approach–avoidance pattern of AB on the visual probe task may appear incompatible with findings from studies that used the modified Stroop, which revealed elevated AB for alcohol words in problem drinkers, regardless of whether or not they were tested in clinical settings and/or were attempting to remain abstinent at the time (Cox, Fadardi, & Pothos, 2006). However, slower color-naming on the modified Stroop could reflect an aversive response to the stimuli, or a combination of appetitive and aversive responding, that is, ambivalence (Yiend, 2010). Consistent with this argument, Greenaway, Mogg, and Bradley (2012) found that, in a sample of pregnant women, the degree of Stroop interference for smoking words was associated with both appetitive (favorable attitudes to smoking) and aversive (fear of harm to the fetus) evaluations of smoking. Thus, when assessed with the modified Stroop task, AB in substance users who are attempting to remain abstinent may (at least partly) reflect aversive motivational processing of those words. The same may apply to ERP measures, which are equally sensitive to appetitive and aversive stimuli (Briggs & Martin, 2009). As previously noted, ERPs in substance users are of greater magnitude when they are viewing substance cues, regardless of whether those individuals are seeking treatment (and motivated to remain abstinent), or not (Littel et al., 2012).

A similar approach–avoidance pattern of AB may be observed in obese participants who experience motivational conflict about food (see Roefs et al., 2015; Werthmann, Jansen et al., 2015), One study used an eye tracking task and demonstrated this approach–avoidance pattern of AB for food cues in obese participants who were concerned about their weight, relative to normal weight controls who were less concerned about their weight (Werthmann et al., 2011). Another study demonstrated attentional avoidance of food pictures in obese patients who were awaiting bariatric surgery (Giel et al., 2014). Even in people who are not obese, mindsets are likely to fluctuate between anticipated hedonic enjoyment of food and the anticipated (negative) health consequences of consuming unhealthy foods, and these fluctuations could lead to variation in the nature and magnitude of AB over time within individuals (see Meule et al., 2013; Werthmann, Jansen, & Roefs, 2016). Unfortunately, very little is known about the association between AB for food and aversive responses to food-related stimuli that accompany fear about gaining weight, and this as an important topic for further investigation.

To summarize, the studies described in this section suggest that the motivational processes that contribute to AB in obesity and addiction may be more complicated than claimed by existing theories. Aversive processing of substance-related cues associated with motivational conflict regarding drugs or overeating could make an important contribution in addicted patients who are attempting to maintain abstinence, and in obese participants who are motivated to lose weight.

Integration: Toward a New Theoretical Account of AB in Obesity and Addiction

In this section, existing theories are integrated with observations made throughout this paper to generate a novel account of the role of AB in obesity and addiction. This account can explain findings that are incompatible with predictions made by existing theories. Figure 1 presents a schematic overview of the account, and its key features are described in the figure legend.

A key tenet of this account is that AB arises from momentary evaluations of substance cues: if those cues are evaluated positively, or negatively, or both simultaneously (ambivalence), then they will capture the attention. Importantly, the evaluation of substance-related cues is likely to vary from moment to moment depending on current motivational orientations to consume the substance or to refrain from consuming it. The proposed key role for stimulus evaluation in AB is informed by classic research on emotion and attention, which demonstrates

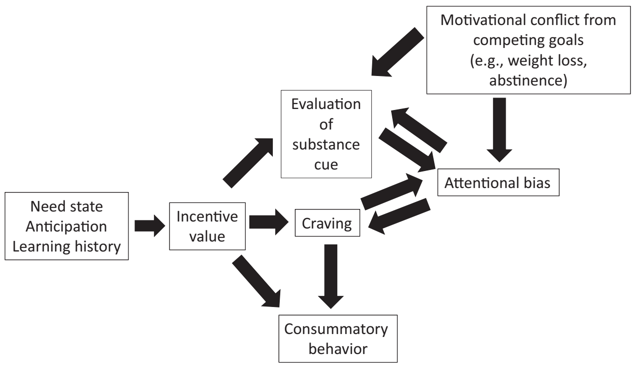

Figure 1. A model of the role of attentional bias in obesity and addiction. *Note*. Attentional bias for a substance-related cue arises when that cue is evaluated either positively or negatively, or both (ambivalence). Importantly, it is the overall strength of that evaluation, rather than its valence, that determines the magnitude of attentional bias (although this may depend on the task used; see text). Positive evaluations of substance-related cues arise as an output of the incentive value of the substance at that moment in time. Subjective craving and consummatory behavior are also outputs of the incentive value of the substance, which explains why attentional bias, cue evaluations, craving and proximal consummatory behavior tend to covary. Substance incentive value is itself determined by multiple factors including biological or emotional "need state" (e.g., caloric restriction, nicotine withdrawal), the perceived availability of the substance ("anticipation"), and the presence of environmental cues that have been paired with the substance ("learning history"), Negative evaluations of substance-related cues arise when people experience motivational conflict between the goal to consume the substance and the goal to control their behavior, such as a goal to lose weight or to abstain from drugs. We also suggest that, in these circumstances, people may attempt to override or control their attentional bias. The model also predicts reciprocal causal relationships between attentional bias and craving, that craving can increase the vigor with which consummatory behavior is pursued, and that attentional bias modification may change evaluations of substance-related cues. Finally, the model predicts an approach–avoidance pattern of attentional bias if cues are evaluated positively and negatively at the same time (i.e., ambivalence), although this pattern can only be detected when using the visual probe task with concurrent eye movement monitoring, and is not depicted in the figure. It is important to clarify that this is a model of attentional bias and its determinants and consequences, and we acknowledge that the processes depicted in the model (particularly substance incentive value and motivational conflict) can influence behavior through many different mechanisms, including but not limited to attentional bias.

that strongly valenced stimuli (both positive and negative) capture attention in proportion to the degree of physiological arousal that they evoke (see Lang, Bradley, & Cuthbert, 1998). It is also consistent with theoretical accounts of AB for negatively valenced stimuli in healthy individuals and those with anxiety and depression, which claim that AB for those stimuli arises from strong negative evaluations and the increased arousal that accompanies those evaluations (see Yiend, 2010).

A further prediction is that the overall strength of the evaluation of a substance-related cue, rather than its valence (positive, negative, or both [ambivalent]), determines the magnitude of AB when it is assessed with the modified Stroop task or ERP measures. It may be possible to infer the valence of the evaluation when using the visual probe task with concurrent eye movement monitoring, with strong positive evaluations leading to a bias to maintain gaze on substance-related stimuli, and ambivalent evaluations leading to an approach–avoidance pattern, but this speculation awaits empirical testing. The claim that perceived valence of substance-related cues contributes to AB is supported by demonstrations that AB for substance-related cues is accompanied by a tendency to perceive those cues as pleasant (Bradley, Field, Mogg, & De Houwer, 2004; Brignell, Griffiths, Bradley, & Mogg, 2009; Littel et al., 2012; Mogg, Bradley, Field, & De Houwer, 2003; Nijs, Franken, & Muris, 2008). In line with the previous discussion about motivational conflict, negative evaluations of substance-related cues should also contribute to AB for those cues, particularly in populations who experience motivational conflict. This prediction should be a priority for empirical testing.

What determines that a substance-related cue will be evaluated positively? Informed by existing accounts of motivated behavior (see Dickinson & Balleine, 2010), the present account assigns a central role to the incentive value of the substance at that moment in time. Incentive value is itself determined by a combination of internal need states (e.g., caloric deprivation, nicotine withdrawal), the perceived availability of the substance ("anticipation"), and the presence of environmental cues that have been associated with that substance ("learning history"). Importantly, it is argued that the momentary incentive value of the substance yields two additional outputs, in addition to positive evaluations of substance cues: (a) a subjective output (craving or hunger); and (b) a behavioral output (consummatory behavior).

Given that substance incentive value fluctuates over time, the present account might explain the observation that AB is imperfectly associated with between-groups differences in drug use or obesity, but it is closely associated with subjective motivational state and consummatory behavior that occurs in the near future. A further prediction that can be generated is that AB is not necessary to translate increased substance incentive value into behavior: if substance incentive value is high, a person would still consume the substance even if their AB could be blocked (if they were prevented from maintaining their attention on substance cues; see Hogarth & Chase, 2013). Despite this, findings from the available ABM studies suggest that there are probably reciprocal causal relationships between the strength of AB and subjective craving. These reciprocal relationships could eventually cause craving to rise to such a level that it becomes "irresistible", and thereby increases the probability of engaging in consummatory behavior.

As detailed above, an important prediction is that substance-related cues will be evaluated negatively or ambivalently in people who experience motivational conflict between desire to consume the substance and goals to change their behavior (e.g., limit food intake in order to lose weight, or stop drinking alcohol), and these negative evaluations will generate AB for those cues. Consideration of this issue might account for the observed approach–avoidance pattern of AB that is seen on the visual probe task in alcohol-dependent patients who are receiving treatment, and emerging evidence that a similar pattern is seen in obese patients who are trying to lose weight. It might also explain why studies that used the modified Stroop task or ERP measures revealed comparable patterns of AB in people who were attempting to change their behavior and those who were not, because appetitive and aversive responses to the cues yield equivalent patterns of AB on these measures. A related but distinct issue is that goals to control behavior and associated worry could prompt strategic attempts to control or override AB, but these strategies could paradoxically increase AB, or at least some components of it (Littel & Franken, 2011; Meule et al., 2013; Yiend, 2010). Therefore, motivational conflict may influence AB through two mechanisms, an automatic mechanism that operates through altered evaluations of those cues, and a strategic mechanism in which people attempt to change their AB directly.

This account also suggests possible mechanisms through which ABM might indirectly influence appetitive behavior. First, given that stimuli can be devalued if attention is repeatedly shifted away from them (Fenske & Raymond, 2006), one possibility is that repeated sessions of ABM may alter evaluations of substance stimuli. In turn, this could reduce the capacity of representations of that substance to evoke AB, craving, and motivated behavior. If so, this would place ABM alongside other novel behavioral interventions for addiction and overeating such as cue avoidance training (Wiers, Eberl, Rinck, Becker, & Lindenmeyer, 2011) and inhibitory control training (Houben, Nederkoorn, Wiers, & Jansen, 2011; Veling, van Koningsbruggen, Aarts, & Stroebe, 2014), which may also change behavior through stimulus devaluation (Veling, Holland, & van Knippenberg, 2008). An alternative mechanism, which could operate alongside the first, is that ABM could interfere with the rumination and elaboration process that causes craving to escalate, and thereby reduce the likelihood that subjective craving could cross the threshold needed to trigger consummatory behavior (Franken, 2003; Hofmann & Van Dillen, 2012). According to this explanation, ABM may be able to prevent craving from increasing in strength.

To summarize, the account of AB described here and depicted in Figure 1 may account for findings in the AB literature that are problematic for existing theories. First, the contention that AB is determined by momentary evaluations of substance-related cues might account for inconsistent between-groups differences in AB. This is because within-subject differences in evaluations of substance-related cues at that moment in time may be much more influential determinants of AB than more stable between-subjects differences, so the former tend to mask the effects of the latter. Second, the model might account for the lack of predictive validity of AB for future behavior when the interval between the two is long, because the stimulus evaluations that underlie AB at one time and one treatment context (e.g., in an addiction clinic) are likely to be very different from the stimulus evaluations that underlie AB several days, weeks or months later, and when assessed in a different context (e.g., outside the clinic, when drugs are available). Third, the model may account for the inconsistent effects of ABM on behavior, because ABM is unlikely to have a dramatic effect on the strong incentive value attributed to substances that determines AB, craving and behavior. In other words, ABM may target an output of the motivational processes that determine behavior, but it may not directly influence the underlying motivational processes. Finally, although AB is robustly associated with subjective craving and hunger and is therefore at least partly a marker of appetitive motivational processes, it is important to note that ostensibly "appetitive" disorders such as obesity and addiction are characterized by motivational conflict about the problem behavior. These aversive motivational processes could also contribute to AB for substance-related stimuli, and consideration of this issue might explain the characteristics and underlying determinants of AB in people who are addicted or obese and are motivated to change their behavior.

Novel Predictions and Suggestions for Future Research

The model outlined in Figure 1 generates the following predictions that can be empirically tested in future research.

1. The Predictive Validity of AB for Future Behavior

According to the model, both AB and behavior are outputs of the incentive value of the substance at that moment in time, which is itself influenced by several factors. Therefore, the predictive validity of AB should be maximal when it is measured soon before the behavior of interest, and in the same context. Experience sampling methods may be particularly suitable for testing this prediction (see Marhe et al., 2013).

Related to this, the model does not predict any association between AB and future behavior when there is a mismatch between substance incentive value when AB is measured, and substance incentive value when behavior is measured. In most of the prospective addiction studies, AB was measured in contexts in which substance incentive value was likely to be very low; for example, in alcohol-dependent patients who were receiving inpatient detoxification treatment. This is a mismatch with the likely incentive value of alcohol later, when the person was outside of the treatment setting and alcohol was available to consume.

2. The Relationship Between AB for Substance Cues and the Perceived Valence of Those Cues

Similar patterns of AB should be seen in people who experience motivational conflict about their behavior (e.g., obese people who want to lose weight, alcohol-dependent patients who want to abstain) and those who do not, when assessed with the modified Stroop task or ERP measures. This is because these tasks cannot distinguish between AB that is determined by positive and negative evaluations of substance-related cues. However, group differences in AB should be apparent on a visual probe task with concurrent eye movement monitoring, as we would expect to see an approach–avoidance pattern of AB in the former group but a more consistent AB in the latter group. The model makes novel predictions about the evaluative judgments that underlie AB in these different groups. In people who experience motivational conflict, AB should be predicted by the strength of negative rather than positive evaluations of substance cues. Whereas, in people who are not motivated to change their behavior, the strength of positive evaluations of substance cues should be the best predictor. Related to this point, researchers should be mindful of the possibility that some participants could evaluate substance cues negatively, and consider this when preparing stimulus materials for AB research. For example, a photograph of a slice of pizza that is "swimming" in grease may be intended to evoke an appetitive response, but obese people who are attempting to lose weight could evaluate it negatively.

3. AB Should Be Sensitive to the Perceived Valence of Substance Cues

To test this prediction, evaluative conditioning procedures could be used to pair substance-related pictures with negative images, which should alter the valence of the substance pictures (Houben, Havermans, & Wiers, 2010). When assessed with a visual probe task with concurrent eye movement monitoring, AB for the substance pictures should change in line with changes in their perceived valence.

4. More Comprehensive Investigations of the Effects of AB on Goal-Directed Behavior

The model predicts that substance cues will be able to increase consummatory behavior even if AB to those cues is blocked by preventing people from focusing their attention on them (see Hogarth, Dickinson, Janowski, Nikitina, & Duka, 2008; Hogarth, Dickinson, & Duka, 2009). However, if participants can maintain their attention on those cues before they are able to consume the substance, they will consume more compared to a group that was not given the opportunity to express AB, and this effect will be mediated by elevated craving.

5. The Mechanisms Through Which ABM Influences Behavior

The model suggests two indirect mechanisms through which ABM may influence consummatory behavior. One possibility is that participants who receive multiple sessions of "avoid substance" ABM would report a reduction in the perceived positive valence of cues used during ABM (Veling et al., 2008), which would in turn mediate the effects of ABM on behavior. An alternative prediction is that ABM "blunts" subjective craving, that is, prevents it from increasing in strength, and this blunting effect mediates the effect of ABM on behavior. These are important questions for future research, and it is also important to investigate if the effectiveness of ABM depends on the context in which it is administered (in the clinic vs. elsewhere), as has been reported for ABM for anxiety disorders (Linetzky, Pergamin-Hight, Pine, & Bar-Haim, 2015; see also Cristea, Kok, & Cuijpers, 2015).

Clinical Implications and Limitations

The theoretical synthesis presented here has implications for clinicians and health psychologists. Most importantly, AB is reframed as primarily an output of the motivational processes that determine behavior, rather than a direct determinant of that behavior itself. The most obvious implication of this is pessimism regarding the potential of ABM as a behavior change intervention. Two mechanisms are described through which ABM might lead to behavior change, but neither is likely to have a substantial impact. First, if ABM alters the perceived valence of substance-related cues, this effect is likely to be very small and would probably be dwarfed by other influences on substance incentive value such as biological "need" (e.g., caloric restriction), perceived availability, and negative mood. Second, if ABM exerts its effects through suppression of craving, one implication is that participants should complete ABM sessions only when they are experiencing strong cravings, because ABM administered when craving is low is unlikely to be effective (see Kerst & Waters, 2014). Despite this pessimistic picture, it is important to note that research on ABM is in its infancy, and results from adequately powered clinical trials with appropriate control conditions are awaited before a definitive judgment is made on its clinical potential.

A further implication is that momentary fluctuations in AB may serve as an "early warning signal" for temptations to consume substances in the near future, a signal that may precede increases in subjective craving or desire (Marhe et al., 2013; Waters et al., 2012). If the findings reported by Marhe et al. (2013) could be replicated and extended to other populations (e.g., people who are overweight and are attempting to lose weight), there is the potential to develop assessments of AB into smartphone apps that people could complete throughout the day. If AB increases it would be a warning signal that they should take action to cope with imminent temptation, such as reminding themselves of their goals (e.g., to lose weight, or to avoid alcohol) and perhaps reinforce any coping skills that they are currently using.

Finally, the model suggests that measurement of AB in clinical settings as people receive treatment may not be a useful predictor of future behavior, particularly for addictions. It may be possible to harness the predictive validity of brain activity that is associated with AB to identify individuals who are likely to need additional help to achieve their goals, or to identify whether the development of attentional avoidance is associated with motivation to change behavior as treatment progresses (see Morgenstern, Naqvi, Debellis, & Breiter, 2013).

Summary and Conclusions

This critical discussion of the literature on AB in obesity and addiction suggests that the stability of AB and its influence on behavior have been overestimated, and the contributions of current substance incentive value and motivational conflict regarding the behavior have been underestimated. According to the theoretical synthesis described in this paper, AB is reframed as an output of the evaluation of substance-related cues, something that is itself determined by both the current incentive value of the substance as well as motivational conflict arising from goals to control behavior. This account suggests that AB does not have a direct causal influence on behavior, but it permits the possibility that it may have an indirect influence, and specifies the psychological mechanisms that may underlie this. Further research is required to confirm or refute predictions generated by this account, and to enable its modification in the future.

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Received March 3, 2015
Revision received May 27, 2016
Accepted May 27, 2016 ■