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Alcohol-related stimuli reduce inhibitory control of behavior in drinkers

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Abstract

Rationale—Poor behavioral control and heightened attentional bias toward alcohol-related stimuli have independently received considerable attention in regard to their roles in alcohol abuse. Theoretical accounts have begun to speculate as to potential reciprocal interactions between these two mechanisms that might promote excessive alcohol consumption, yet experimental evidence is lacking.

Objectives—The objective of the study was to integrate these two lines of research through the development of a novel laboratory task that examines the degree to which alcohol cues serve to disrupt mechanisms of behavioral control.

Methods—Fifty adult drinkers were recruited to perform the attentional bias–behavioral activation (ABBA) task. The ABBA task, an adaptation of traditional cued go/no-go tasks, is a reaction time model that measures the degree to which alcohol-related stimuli can increase behavioral activation of a drinker and reduce the ability to inhibit inappropriate responses. Participants also completed a novel measure of attentional bias, the scene inspection paradigm (SIP), that measures fixation time on alcohol content imbedded in complex scenes.

Results—As hypothesized, the proportion of inhibitory failures on the ABBA task was significantly higher following alcohol images compared to neutral images. Correlational analyses showed that heightened attentional bias on the SIP was associated with greater response activation following alcohol images on the ABBA task.

Conclusions—These findings suggest that alcohol stimuli serve to disrupt mechanisms of behavioral control, and that heightened attentional bias is associated with greater disruption of control mechanisms following alcohol images.

Keywords

Alcohol; Behavioral control; Attentional bias; Response activation; Inhibition

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Conflicts of interest The authors have no conflict of interest to declare.

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Introduction

Research on alcohol abuse has begun to focus considerable attention on the role of cognitive mechanisms in excessive and harmful alcohol consumption. One specific cognitive factor that has been shown to be strongly associated with alcohol abuse is that of behavioral control (Fillmore 2003; Finn et al. 1994; Lyvers 2000). Generally speaking, impaired control mechanisms increase the difficulty alcohol abusers often experience in suppressing urges to consume the drug. As such, disinhibited consumption persists, despite the occurrence of numerous negative alcohol-related consequences. A second cognitive factor that has been found to be relevant to alcohol abuse is that of cognitive biases related to alcohol and alcohol-related stimuli (Field and Cox 2008; Ryan 2002; Stacy and Wiers 2010). Alcohol abusers have been shown to focus increased attention towards alcohol-related cues (i.e., "attentional bias") compared to light or non-drinkers, and to display a biased interpretation of such cues as being more positive or arousing. Moreover, attention directed towards alcohol-related stimuli is thought to increase urges to consume alcohol, thereby promoting increased use. Both cognitive mechanisms of behavioral control and attentional bias are often examined both as chronic, stable characteristics of an individual, and as malleable factors that are sensitive to environmentally-influenced fluctuations (Field et al. 2010; Fillmore 2003; Lyvers 2000). Moreover, some researchers have begun to speculate as to how these two mechanisms might serve to reciprocally influence each other in such a way that would promote excessive consumption (e.g., Goldstein and Volkow 2002). The current study sought to experimentally investigate this potential interaction through the integration of behavioral control and attentional bias models.

Cognitive models of behavioral control date back several decades. Theorists typically describe behavioral control as governed by two independent processes: an activational process and an inhibitory process (Fowles 1987; Gray 1976; Logan and Cowan 1984). The activational process is responsible for executing a behavioral response, whereas the inhibitory process is responsible for inhibiting inappropriate or unwanted behavior. These two processes act in opposition, and behavior is assumed to occur based on the relative strength of each. Laboratory tasks designed to model these two processes (e.g., go/no-go tasks, stop-signal tasks) have been utilized to examine behavioral control in substance abusers (e.g., Bjork et al. 2004; Rubio et al. 2008). These tasks typically require the execution of quick responses to go targets, and the inhibition of responses when stop-signals or no-go targets are presented. Reaction time to go targets provides a measure of response activation, and failure to inhibit responses to no-go targets provides a measure of inhibition. Speed of response is encouraged, facilitating greater response activation and increasing difficulty of inhibition.

Studies of alcohol abuse utilizing these tasks have provided evidence for associations between deficits in behavioral control and greater alcohol consumption and alcohol-related problems. For example, our lab has shown that a greater number of inhibitory failures on a cued go/no-go task is associated with greater alcohol consumption in both adults with ADHD and controls (Weafer et al. 2011). Similarly, Rubio et al. (2008) showed that heavy drinkers displayed slower response inhibition on a stop-signal task compared with moderate drinking controls, and studies using continuous performance tasks show that detoxified

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alcoholics commit more commission errors (i.e., inhibitory failures) compared to controls (e.g., Bjork et al. 2004). Further, the acute impairing effects of alcohol on behavioral control are also well-established, and the disinhibiting effects of the drug are thought to play a role in its abuse potential (Fillmore 2003, 2007). For instance, binge drinkers show greater alcohol-induced impairment of inhibitory control compared to non-binge drinkers (Marczinski et al. 2007), and individual differences in sensitivity to alcohol-induced disinhibition have been shown to predict levels of ad lib alcohol consumption (Weafer and Fillmore 2008). In sum, a wealth of research has provided a strong link between impaired mechanisms of behavioral control and alcohol abuse.

A separate line of research has focused on the role of selective attention for alcohol-related cues in alcohol abuse. Attentional bias for alcohol stimuli is theorized to originate as a result of a history of heavy alcohol use through classical conditioning (Field and Cox 2008; Franken 2003). According to the incentive-sensitization theory (Robinson and Berridge 1993, 2001), as substance-related cues are repeatedly paired with drug administration over a prolonged period of drug use, the cues come to be associated with both drug consumption and motivation for consumption. As a result, drug-related stimuli become increasingly salient for users, resulting in greater attentional orienting towards the cues when they are encountered in the environment. Further, drug-related cues take on high incentive-motivational properties, eliciting increased motivation for, and behavioral activation of drug-seeking and drug-taking.

Several laboratory measures have been developed to assess attentional bias. Recent studies have focused on the visual probe task, which presents alcohol-related and neutral stimuli side by side on a computer screen. Eye-tracking equipment records the amount of time participants spend fixating on each image, and longer fixation on alcohol compared to neutral images is thought to reflect an attentional bias to alcohol-related stimuli (Miller and Fillmore 2010, 2011; Schoenmakers et al. 2008). Studies utilizing this and other similar tasks have provided consistent evidence for greater attentional bias in heavy drinkers compared to light drinkers (Field et al. 2007; Murphy and Garavan 2011; Sharma et al. 2001; Tibboel et al. 2010; Townshend and Duka 2001), and in treatment-seeking alcoholics compared to social drinking controls (e.g., Jones et al. 2006). Additionally, individual difference analyses have shown that magnitude of attentional bias predicts level of consumption and alcohol problem severity in both social drinkers (Ceballos et al. 2009; Fadardi and Cox 2008; Miller and Fillmore 2010; Murphy and Garavan 2011; Weafer and Fillmore under review) and alcoholics (Jones et al. 2006).

To date, research on deficient behavioral control and research on attentional bias in alcohol abusers have each proceeded as fairly independent lines of inquiry. However, the potential confluence of these two cognitive mechanisms in the etiology and maintenance of drug abuse has been well recognized for some time (Dawe et al. 2004; Goldstein and Volkow 2002; Jentsch and Taylor 1999). These mechanisms are hypothesized to work simultaneously, and potentially interactively, to increase the likelihood of unregulated alcohol-seeking and prolonged alcohol consumption. For instance, attention directed towards alcohol cues could serve to acutely disrupt mechanisms of behavioral control. That is, the stronger the motivational response elicited by the cue, the more difficult it should be

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to inhibit a behavioral response to seek out the cue (and the drug). As such, in heavy drinkers, attention towards alcohol-related stimuli might result in increased behavioral activation and impaired mechanisms of inhibitory control. However, despite speculation regarding the disruptive effect of attentional bias on behavioral control mechanisms, this hypothesis has received little experimental investigation.

For the current study, we sought to develop a novel behavioral task to investigate the hypothesized disruptive effect of alcohol-related stimuli on inhibitory and activational mechanisms of behavior. We modified a cued go/no-go task that has been used extensively in alcohol abuse research (Fillmore 2003, 2007). The task presents cues that signal a response will be required. The cues serve to increase response activation and to make inhibition difficult on the occasional instances when the response must be suddenly inhibited. In traditional cued go/no-go tasks, the cues are typically arbitrary symbols (e.g., geometrical shapes). However, in our adapted task, the attentional bias–behavioral activation (ABBA) task, alcohol-related images serve as cues. As such, the ABBA task allows for an experimental examination of the degree to which alcohol cues themselves serve to disrupt behavioral control. It was hypothesized that for individuals with a history of moderate to heavy alcohol consumption, alcohol cues would increase response activation (speed reaction time) and impair inhibitory control (increase the frequency of inhibitory failures).

To date, only a handful of studies have examined behavioral control mechanisms in response to alcohol cues. Noel et al. (2007) administered a go/no-go task that presented alcohol-related and neutral words as targets and distracters. Overall, participants responded faster to alcohol targets compared to neutral targets, and more commission errors were observed to alcohol distracters. Rose and Duka (2008) administered a similar go/no-go task that presented alcohol-related and neutral pictures as targets. Here, the authors reported a slowing effect of alcohol stimuli on response activation and no effect of alcohol stimuli on inhibitory errors. In a third study, Nederkoorn et al. (2009) examined performance on a stop-signal task in which stimuli consisted of alcohol-related and neutral pictures; however, results showed no effect of alcohol stimuli on response inhibition. Although it is unclear why the two studies that utilized pictures as stimuli (i.e., Nederkoorn et al. 2009; Rose and Duka 2008) failed to observe a disruptive effect of alcohol cues on behavioral control, it is important to note that neither study included an independent measure of attention-al bias. Alcohol stimuli would only be expected to affect behavioral control in individuals who have developed some degree of attentional bias to alcohol-related cues. With no assessment of such a bias, it is unknown if alcohol images would have captured attention in order to influence the participants' behavior in these studies.

The current study included an independent measure to verify attentional bias in participants, and to test the hypothesis that individuals who display greater attentional bias to alcohol stimuli would also display a greater disruption of behavioral control in response to alcohol cues. The scene inspection paradigm (SIP), a novel measure of attentional bias developed in our laboratory, presents a series of images consisting of commonly encountered real-life scenarios (e.g., party, dinner setting), which contain an element of alcohol-related content. Participants inspect the images and eye-tracking software is used to monitor their viewing patterns. The total amount of time a participant spends focusing on the alcohol content is

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measured, and longer viewing time on alcohol content represents a greater attentional bias. This measure of attentional bias differs from traditional visual probe measures, in that it presents alcohol cues within a more “real-life” and ecologically valid scenario. Specifically, the SIP presents alcohol cues as they are encountered in the environment (e.g., an individual carrying a pitcher of beer; a glass of beer on a table in a restaurant). This allows for a measurement of the degree to which alcohol stimuli capture attention in the context of other interesting, competing stimuli (e.g., human faces), and as such might provide a better understanding of how attention towards these cues operates to promote alcohol consumption outside of the laboratory.

In sum, the current study aimed to integrate two lines of research involving mechanisms theorized to be associated with alcohol abuse (i.e., impaired behavioral control and attentional bias) through the utilization of two novel laboratory tasks. A sample of moderate to heavy drinkers was recruited to perform the ABBA task and the SIP. It was hypothesized that participants would display greater disruption of behavioral control in the presence of alcohol cues, as evidenced by greater response activation and impaired response inhibition. Further, we hypothesized that those whose behavioral control was most disrupted by alcohol images on the ABBA task would also display the greatest attentional bias on the SIP.

Methods

Participants

Fifty adult beer drinkers (20 women and 30 men) between the ages of 21 and 29 (mean age=23.9, SD=2.6) were recruited to participate in this study. Screening measures were conducted to determine medical history and current and past drug and alcohol use. Any volunteers who self-reported head trauma, psychiatric disorder, or substance abuse disorder were excluded from participation. Volunteers were recruited via notices placed on community bulletin boards and by university newspaper advertisements. The University of Kentucky Institutional Review Board approved the study, and participants received $30 for their participation.

Materials and measures

Attentional bias–behavioral activation task—The ABBA task, a modified cued go/no-go reaction time task, was operated using E-prime experiment generation software (Psychology Software Tools, Pittsburgh, PA) and was performed on a PC. A trial involved the following sequence of events: (a) presentation of a fixation point (+) for 800 ms; (b) a blank white screen for 500 ms; (c) a cue image (alcohol or neutral), displayed for one of five stimulus onset asynchronies (SOAs 0100, 200, 300, 400, and 500 ms); (d) a go or no-go target, which remained visible until a response occurred or 1,000 ms had elapsed; and (e) an intertrial interval of 700 ms.

The cues consisted of alcohol-related images (e.g., beer can, six-pack of beer bottles) or neutral images (e.g., stapler, paper towel roll). These were 15 cm×11.5 cm images presented in the center of the computer monitor against a white background. The alcohol beverage type was always beer. After an SOA, the cue image turned either solid green (go target) or

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solid blue (no-go target). Participants were instructed to press the forward slash (/) key on the keyboard as soon as a green (go) target appeared and to suppress the response when a blue (no-go) target was presented. Key presses were made with the right index finger. A schematic of a trial in which an alcohol cue turns into a go target is presented in Fig. 1.

The task consisted of two conditions: *alcohol go* condition and *neutral* go condition. In the alcohol go condition, alcohol images turned into the go target on 80% of trials and turned into the no-go target on only 20% of trials. Therefore, alcohol images operated as go cues, based on the high probability that they would signal go targets most of the time. As such, these images should speed reaction time (RT) to the go targets, but also increase failures to inhibit the response when the no-go target is occasionally presented. By contrast, in the neutral go condition, the opposite cue image-target pairings were presented. Therefore, in this condition, neutral images serve as go cues, producing faster RT to go targets, but more inhibitory failures to the occasional presentation of no-go targets. By comparing the alcohol go condition and neutral go condition, the task measures the degree to which alcohol-related go cues elicit greater response activation but poor inhibitory control, compared to neutral go cues.

A test consisted of 250 trials, split into five blocks of 50 trials each. For each trial, the computer recorded whether a response occurred and, if so, the RT in milliseconds was measured from the onset of the target until the key was pressed. To encourage quick and accurate responding, the computer presented feedback to the participant during the intertrial interval by displaying the words *correct* or *incorrect* along with the RT in milliseconds. Omission errors (when participants failed to respond to go targets) were also recorded. These were infrequent and occurred on less than 0.005% of go target trials (i.e., less than one trial per test). RTs from omission errors were excluded from analyses. Each block required approximately 2.5 min to complete, and blocks were separated by 30 s breaks, for a total test time of approximately 15 min.

Scene inspection paradigm—Attentional bias was measured by the SIP, operated on a Tobii T120 eye tracker (Tobii Technology, Sweden). Cameras are embedded into the Tobii monitor, providing an unobtrusive measure of eye movement that allows participants to sit comfortably, approximately 60 cm in front of the computer, with free range of head and neck motion. Participants were presented with 20 images (18.4 cm×14.5 cm) on the monitor in random order for 15 s each. They were instructed to look at the images closely the entire time they were on the screen, ostensibly to prepare for a picture recognition test later in the session. Ten of the images portrayed common real-life scenes that included an element of alcohol-related content (e.g., a place setting at a restaurant containing beer bottles, people drinking beer in a bar). The alcohol content of the images was restricted to 15–30% of the total image size, and the alcohol beverage type was always beer. The remaining ten filler images also presented common real-life scenes that were matched for complexity, but contained no alcohol-related content.

The dependent measure of interest was the total amount of time participants spent focused on the alcohol-related content during presentation of the ten critical images. Alcohol areas of interest (AOIs) were defined within the Tobii Visualization window by marking the area

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surrounding the specific alcohol-related content (e.g., bottle of beer) in each scene. The eye-tracking equipment recorded the amount of time in seconds each participant spent looking within each AOI. The Tobii software provided a measure of total visit duration, which gave the total time each participant spent viewing alcohol-related content, summed across all of the ten critical images. Together, the critical images were presented for a total of 150 s (15 s for each of the ten images), allowing for the total visit duration in AOIs to range from 0 to 150 s. Longer total visit duration indicated greater attentional bias towards alcohol-related content of the images.

Barratt Impulsiveness Scale—Participants completed the Barratt Impulsiveness Scale (Patton et al. 1995) to provide a self-report measure of impulsivity. Participants indicated how typical each of 30 statements (e.g., “I am self-controlled”) is for them on a 4-point Likert scale. Higher scores indicated greater total levels of impulsiveness.

Time line follow-back—Participants completed the time line follow-back (TLFB; Sobell and Sobell 1992), a retrospective time line calendar of their alcohol consumption for the past 3 months, to assess daily patterns of drinking, including number of binge episodes. The measure uses “anchor points” to structure and facilitate participants’ recall of past drinking episodes. For each day, participants estimated the number of standard drinks they consumed and the number of hours they spent drinking. This information, along with gender and body weight, was used to estimate the resultant blood alcohol concentration (BAC) obtained for each drinking day. This was done using well-established, valid anthropometric-based BAC estimation formulae that assume an average clearance rate of 15 mg/dl per hour of the drinking episode (McKim 2007; Watson et al. 1981). These formulae have been used in previous studies and have been shown to yield high correlations with actual resultant BACs obtained under laboratory conditions (Fillmore 2001). Any day in which the estimated resultant BAC was 80 mg/100 ml or higher was classified as a binge episode (NIAAA 2004). The time line follow-back (TLFB) provided three measures of drinking habits over the past 3 months: (a) binge days (total number of binge episodes); (b) drinking days (total number of days alcohol was consumed); (c) total drinks (total number of drinks consumed over the 3 months).

Procedure

Interested volunteers responded to study advertisements by calling the laboratory to participate in an intake-screening interview conducted by a research assistant. At that time, they were informed that the purpose of the study was to examine performance on cognitive tasks. Volunteers were asked to report their preferred alcoholic beverage (beer, wine, or liquor). Because all alcohol-related stimuli consisted of beer images, only those reporting beer as their preferred beverage were eligible for study participation. Eligible participants made appointments to attend the 1.5-h testing session in the Behavioral Pharmacology Laboratory of the Department of Psychology. All participants were tested individually. At the beginning of the session, participants provided informed consent for participation. Participants’ heights and weights were measured, and urine samples were tested for drug metabolites, including amphetamine, barbiturates, benzodiazepines, cocaine, opiates, and tetrahydrocannabinol (ON trak TesTstiks, Roce Diagnostics Corporation, Indianapolis, IN,

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USA). Breath samples were measured by an Intoxilyzer, Model 400 (CMI, Inc., Owensboro, KY, USA) to verify a zero BAC.

Men and women were randomly divided into two groups upon initiation into the study. Half of participants were assigned to the alcohol go task condition, and half were assigned to the neutral go condition, such that gender make-up was equivalent across groups. All participants first performed the SIP, which took approximately 5 min to complete, followed by the ABBA task. Task order was kept constant to prevent any carry over influence of ABBA task condition assignment on SIP performance. Participants completed questionnaire measures, including demographics, impulsivity, and alcohol consumption measures. Lastly, participants were debriefed and compensated for their participation.

Criterion measures and data analyses

ABBA (behavioral control)—Performance in the alcohol go condition and the neutral go condition was compared to test the degree to which alcohol images increased response activation and decreased response inhibition relative to neutral images. Both RT and the proportion of inhibitory failures (p-inhibitory failures) were analyzed by between-groups *t* tests.

SIP (attentional bias)—The primary dependent variable for the SIP was total visit duration on AOIs during presentation of the ten critical images. Correlational analyses were conducted to analyze the degree to which time spent focusing on alcohol stimuli in the SIP predicted RT and p-inhibitory failures on the ABBA, separately for the alcohol go and neutral go conditions.

Results

Demographics, trait impulsivity, and drinking habit measures

Table 1 summarizes demographic data, trait impulsivity, and drinking habit measures for participants in the alcohol go and neutral go conditions. The groups did not differ significantly in age, trait impulsivity, or in any measure of alcohol consumption over the past 90 days as reported on the TLFB (*ps* >0.25). The table shows that participants were frequent drinkers, reporting alcohol consumption on a mean of approximately 1/3 of the past 90 days. Moreover, on average, over 1/3 of those drinking days were binge episodes. These self-reported drinking patterns provide confirmation of participants' frequent moderate to heavy alcohol consumption.

ABBA task performance

Reliability—Intraclass correlation coefficients were calculated to estimate the reliability of individual participants' performance for both task conditions of the ABBA task. For each participant, mean response activation and inhibition scores were calculated for each of the five test blocks, and reliability of their performance across blocks was estimated by calculating the coefficients of consistency for each measure using Hoyt's formula (McGraw and Wong 1996). For the alcohol go condition, RT and p-inhibition failures showed consistency coefficients of 0.94 and 0.92, respectively. For the neutral go condition, RT and

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p-inhibition failures showed consistency coefficients of 0.95 and 0.77, respectively. Thus, individual differences among participants' performance showed consistency over the five test blocks in both task conditions.

Response activation and inhibition following go cues—Mean RT following go cues for the alcohol go and neutral go conditions are presented in Fig. 2 (left panel). The figure shows that mean RT was slightly faster to go targets that followed alcohol images compared to those that followed neutral images; however, a between-groups *t* test showed that this was not a significant difference (p=.34). Mean p-inhibitory failures to no-go targets that followed go cues are presented in Fig. 2 (right panel). The figure shows greater frequency of inhibitory failures following alcohol images compared to neutral images. A between-groups *t* test confirmed that mean p-inhibitory failures were greater in the alcohol go condition compared to the neutral go condition, compared to the neutral go condition, $t(48)=2.2$, $p=0.03$, $d=0.63$.

Response activation and inhibition following no-go cues—RT was expected to be slowed and p-inhibitory failures infrequent following no-go cues, and as such cue image type was expected to have little influence on response activation and inhibition. Mean RT and p-inhibitory failures to no-go cues are presented in Table 2. The table shows that, as expected, mean RT and p-inhibitory failures were comparable in both conditions, and between-groups *t* tests showed no difference in mean RT (p=0.75) or p-inhibitory failures (p=0.07) between the conditions.

Scene inspection paradigm

Reliability—Internal consistency of time spent focusing on alcohol images on the SIP task was calculated by a split-half reliability coefficient. The ten alcohol images were split into two sets of five images each (i.e., even-numbered images and odd-numbered images), and yielded a split-half reliability coefficient of 0.83. Thus the degree of attention allocated to alcohol stimuli was reliably observed across images.

Associations with drinking habits—Attentional bias as measured by the SIP was examined in the sample as a whole. Mean attentional bias (i.e., mean time spent fixated on alcohol AOIs) was 59.2 s (SD=12.9). There was considerable variability within the sample, with alcohol fixation time ranging from 25.1 to 90.0 s. In order to validate the SIP as a measure of attentional bias, it was necessary to confirm that participants' alcohol fixation times were associated with their alcohol consumption. To test this, we conducted bivariate correlational analyses between alcohol consumption measures as reported on the TLFB and participants' alcohol fixation time on the SIP. Alcohol fixation time on the SIP showed a significant positive association with participants' number of binge days (r=0.29, p=0.04) and their total drinks consumed (r=0.31, p=0.03) over the past 90 days. Thus, individuals who reported consuming the greatest quantities of alcohol also spent the most time focusing on alcohol-related images in this paradigm. Attentional bias was not related to number of drinking days (i.e., frequency of drinking) over the past 90 days (p=0.73).

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Associations with ABBA performance—We tested the hypothesis that greater attentional bias on the SIP should predict greater response activation and poor inhibitory control following alcohol images on the ABBA task. Mean fixation time on the SIP was comparable for those in the alcohol go (mean=61.1 s, *SD*=14.3) and neutral go (mean=57.2, SD=11.3) conditions, and this was confirmed by a between-groups *t* test (p=0.28). Longer alcohol fixation times were associated with faster RT on the ABBA task for those in the alcohol go condition (r=−0.43, p=0.03), but no association between alcohol fixation times and p-inhibitory failures was observed (p=0.50). Thus, individuals who displayed greater attentional bias also responded faster following alcohol images, but did not display more inhibitory failures. Alcohol fixation times showed no relation to either measure on the ABBA task for those in the neutral go condition (*ps*>0.17).

Discussion

This study integrated two lines of research regarding the roles of behavioral control and attentional bias in alcohol abuse. Specifically, the study examined both the degree to which alcohol images served to disrupt mechanisms of behavioral control and the extent to which individual differences in attentional bias predicted disruption of control in response to alcohol images. Participants performed a novel laboratory task that measured response activation and inhibition following alcohol-related and neutral images. Results showed that inhibitory failures were more frequent following alcohol images compared to neutral images. Further, the study examined attention to alcohol content on a novel measure of attentional bias. Validation for this measure was provided by significant associations between heightened attentional bias on the SIP and greater self-reported measures of quantity of alcohol consumption. Moreover, individual differences in attentional bias predicted response activation, but not response inhibition, following alcohol images on the ABBA task. That is, those who fixated on alcohol content for the longest time on the SIP also displayed the fastest responses following alcohol images on the ABBA task. No significant associations were found regarding attentional bias and response activation or inhibition following neutral images.

These findings provide evidence in support of the hypothesis that, in addition to capturing attention, alcohol cues can disrupt mechanisms of behavioral control, particularly in terms of response inhibition. Moreover, results showed a significant association between heightened attentional bias and greater response activation following alcohol images. Theoretical accounts of attentional bias propose that attention towards alcohol stimuli elicits motivation to seek out and consume alcohol in heavy drinkers (Franken 2003; Ryan 2002). This motivation is thought to increase activation of alcohol-seeking behavior and weaken inhibitory mechanisms necessary to control such behavior. The current findings provide some of the first experimental evidence of impaired behavioral control mechanisms in response to alcohol cues. Further, this disruption was most pronounced in individuals displaying a heightened attentional bias toward alcohol stimuli. This provides support for a general conditioning effect in heavy drinkers that both increases attentional bias towards alcohol stimuli and also results in reduced behavioral control in the presence of those stimuli.

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By integrating two mechanisms that have been primarily tested independently in the past, the current study adds important information regarding the specific means through which both behavioral control and attentional bias might serve to promote alcohol consumption. It is well-established that impaired control mechanisms are associated with alcohol abuse (Fillmore 2003, 2007; Jentsch and Taylor 1999; Lyvers 2000). However, behavioral control has typically been assessed in response to arbitrary stimuli. In terms of "real world" situations, individuals attempting to control alcohol use must do so in the face of meaningful alcohol cues with potentially strong motivational properties. It is important to consider how behavioral control is compromised when alcohol stimuli are encountered, as this provides a more relevant and ecologically valid understanding of disruption of control mechanisms in high-risk alcohol consumption scenarios. As for attentional bias, it is well-established that a more pronounced attentional bias is associated with greater alcohol consumption and alcohol-related problems (Field and Cox 2008). However, causal mechanisms through which a bias towards alcohol cues might promote consumption are not well understood. The current findings provide evidence suggesting that attention to the cues serves to increase response activation and decrease response inhibition. In terms of real world implications, it could be that attention to alcohol cues encountered in the environment could increase behavioral activation towards seeking out alcohol and impair inhibitory mechanisms necessary to suppress or curtail alcohol-seeking and consumption.

To our knowledge, this is the first study to show a disruptive effect of alcohol-related images on behavioral control. Several methodological distinctions exist between the current study and previous studies that similarly examined inhibition in response to alcohol cues (e.g., Nederkoorn et al. 2009; Rose and Duka 2008) that could potentially explain the inconsistencies in findings. First, the current study included the SIP to independently verify attentional bias in participants and, more importantly, to confirm that performance on the ABBA task following alcohol images was related to attentional bias. Further, in the current study, all alcohol stimuli consisted of beer images and only participants who reported beer as their preferred alcoholic beverage were eligible to participate. This ensured that all participants had significant drinking experience with the stimuli presented, and allowed for a more sensitive test of conditioned responses to alcohol stimuli.

The between-subjects design might be a potential limitation of the current study, as it is possible that the groups differed in baseline levels of inhibitory control. However, it is important to note that all participants were recruited from the same population of young adults and randomly assigned to conditions. We obtained comprehensive reports of demographic data, drinking habits, and trait impulsivity, and we were able to show that the groups did not differ on any of these measures, nor did the groups differ in attentional bias as measured by the SIP. However, it will be important for future studies to include an independent measure of inhibitory control to rule out the possibility that differences in performance between groups might be due to pre-existing group differences in inhibitory control. Alternately, the ABBA task could potentially be modified for future studies such that all participants perform both task conditions, allowing for a within-subjects comparison of inhibitory control following both alcohol and neutral cues.

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There are several important questions that can be addressed using the ABBA task and the SIP that were beyond the scope of the present study. For instance, these tasks could be utilized to examine the effects of acute alcohol administration on response activation and inhibition in the context of alcohol cues. The acute disinhibiting effects of alcohol are well-established (Fillmore 2003, 2007), and are thought to play a role in excessive, episodic drinking (i.e., binge drinking) (Fillmore 2007; Marczinski et al. 2007; Weafer and Fillmore 2008). It is likely that alcohol's disinhibiting effects might be even more pronounced when inhibition must take place following alcohol cues. Moreover, this is a more ecologically valid measure of the type of behavioral control necessary to terminate a drinking episode once it has been initiated. That is, the decision to stop alcohol consumption once it has begun is likely to be executed in the presence of alcohol cues. If, as these results suggest, behavioral control is disrupted in response to alcohol stimuli, and if the disruption is even more pronounced in response to alcohol, this could be an important factor in promoting excessive alcohol consumption, particularly for individuals attempting to limit or control their drinking. A second question that should be addressed in future research is how other drug-related stimuli (in addition to alcohol) might produce similar disruption of control mechanisms. Evidence of increased attentional bias toward drug-related stimuli has been reported across several different addictive drugs, including cocaine, heroin, and cigarettes (Chanon et al. 2010; Dunning et al. 2011; Waters et al. 2012). It is possible that attention to these stimuli could also increase response activation and impair inhibitory control, thus contributing to the difficulty abusers of these substances experience in resisting drug use when such stimuli are encountered in the environment. Examination of the degree to which the current findings generalize to other drugs of abuse will provide important information regarding the role of drug-related stimuli in substance use and abuse.

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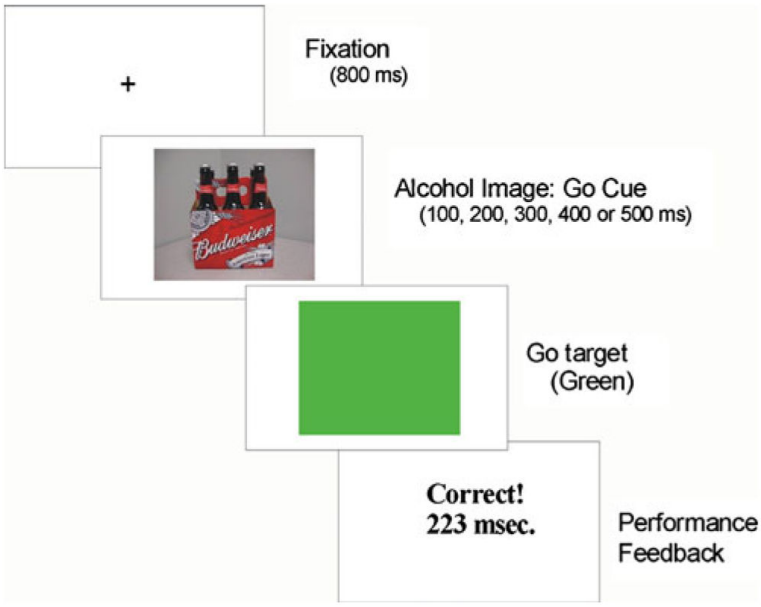

Fig. 1.

Schematic of a trial in the alcohol go condition on the ABBA task. Following the fixation point, an alcohol image is presented. Alcohol images precede go targets on the majority of trials in this condition, and as such alcohol images serve as go cues and increase behavioral activation. The go target is then presented, and the participant executes the response as quickly as possible. The computer provides feedback immediately following the response

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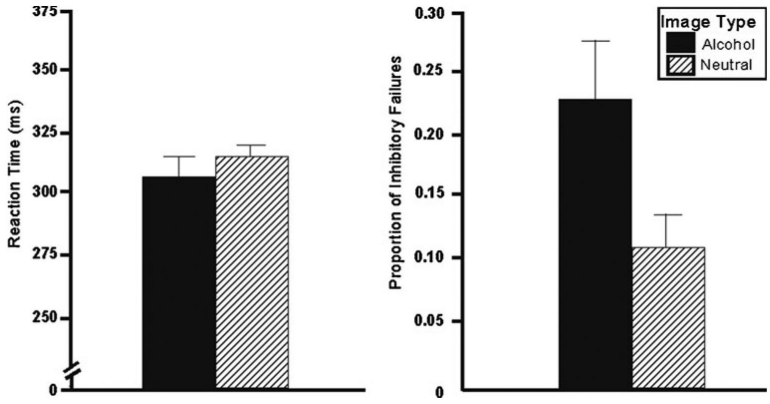

Fig. 2.

Mean RT (*left panel*) and p-inhibitory failures (*right panel*) to go cues following alcohol and neutral images on the ABBA task. *Capped vertical lines* represent standard errors of the mean

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Table 1

Mean demographics, trait impulsivity, and drinking habits by condition

	Condition				Contrasts
	Alcohol go		Neutral go		
	M	SD	M	SD	
Demographics					
Gender (F:M)	10:15		10:15		ns.
Age	23.7	2.2	24.1	2.9	ns.
Barratt Impulsiveness Scale TLFB (past 90 days)	65.4	9.9	62.6	7.0	ns.
Binge Days	11.4	10.1	11.2	11.1	ns.
Drinking Days	28.4	16.1	27.6	13.2	ns.
Total Drinks Consumed	164.9	148.8	127.2	86.1	ns.

Contrasts were tested by one-way between-groups ANOVAs *ns* indicates a significance value of $p>0.05$

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Table 2

Mean reaction time and p-inhibitory failures to no-go cues by image type

	Reaction time		p-Inhibitory failures	
	M	**SD**	**M**	**SD**
Alcohol image	332.8	28.2	0.04	0.04
Neutral image	336.2	45.3	0.08	0.09