Published in final edited form as:

Drug Alcohol Depend. 2016 March 1; 160: 90–96. doi:10.1016/j.drugalcdep.2015.12.033.

Drinkers' memory bias for alcohol picture cues in explicit and implicit memory tasks

Tam T. Nguyen-Louie^a, Jennifer F. Buckman^b, Suchismita Ray^c, and Marsha E. Bates^d

Tam T. Nguyen-Louie: ttn045@ucsd.edu; Jennifer F. Buckman: jrbuckman@rutgers.edu; Suchismita Ray: shmita@rci.rutgers.edu; Marsha E. Bates: meabates@rutgers.edu

^aSDSU/UCSD Joint Doctoral Program in Clinical Psychology, 8950 Villa La Jolla Dr., La Jolla, CA, 858-534-0771

^bCenter of Alcohol Studies, 607 Allison Road, Rutgers University, Piscataway NJ 08854, 848 445-0793, FAX 732 445-3500

^cCenter of Alcohol Studies, 607 Allison Road, Rutgers University, Piscataway NJ 08854, 848 445-9391, FAX 732 445-3500

^dCenter of Alcohol Studies, 607 Allison Road, Rutgers University, Piscataway NJ 08854, 848 445-3559, FAX 732 445-3500

Abstract

Background—Alcohol cues can bias attention and elicit emotional reactions, especially in drinkers. Yet, little is known about how alcohol cues affect explicit and implicit memory processes, and how memory for alcohol cues is affected by acute alcohol intoxication.

Methods—Young adult participants ($N=161$) were randomly assigned to alcohol, placebo, or control beverage conditions. Following beverage consumption, they were shown neutral, emotional and alcohol-related pictures cues. Participants then completed free recall and repetition priming tasks to test explicit and implicit memory, respectively, for picture cues. Average blood alcohol concentration for the alcohol group was 74 ± 13 mg/dl when memory testing began. Two mixed linear model analyses were conducted to examine the effects of beverage condition, picture cue type, and their interaction on explicit and implicit memory.

Results—Picture cue type and beverage condition each significantly affected explicit recall of picture cues, whereas only picture cue type significantly influenced repetition priming. Individuals

---

Correspondence to: Marsha E. Bates, meabates@rutgers.edu.

Contributors:

Tam T. Nguyen-Louie, M.S., took part in the data analysis and interpretation, and drafting and revising of the manuscript. Jennifer F. Buckman, Ph.D., took part in the conception of the project idea, data interpretation, and manuscript revision. Suchismita Ray, Ph.D., took part in the experimental paradigm design, data acquisition, and manuscript revision. Marsha E. Bates, Ph.D., took part in the conception of the project idea, experimental paradigm design, manuscript revision, and provided the final approval for the version submitted.

Conflict of Interest: No conflict declared

Role of Funding Source: Nothing declared

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

in the alcohol condition recalled significantly fewer pictures than those in other conditions, regardless of cue type. Both free recall and repetition priming were greater for emotional and alcohol-related cues compared to neutral picture cues. No interaction effects were detected.

Conclusions—Young adult drinkers showed enhanced explicit and implicit memory processing of alcohol cues compared to emotionally neutral cues. This enhanced processing for alcohol cues was on par with that seen for positive emotional cues. Acute alcohol intoxication did not alter this preferential memory processing for alcohol cues over neutral cues.

Keywords

intoxication; cue reactivity; repetition priming; free recall; emotion

1. INTRODUCTION

Evidence from human and animal studies strongly suggests that emotional memories possess a “privileged status” compared to neutral memories (Cahill and McGaugh, 1995, 1996; Christianson, 1992; LaBar and Cabeza, 2006; Roozendaal, 2000). Preferentially retaining emotionally-laden events and cues (i.e., memory bias), particularly those with negatively charged valence, is likely linked to evolution and survival (Berntsen and Rubin, 2002; Hamann, 2001; Ohman and Mineka, 2001). In addition, individuals with post-traumatic stress disorder (Brewin, 2001; Ehlers and Clark, 2000), depression (Bradley and Lang, 1994; Watkins et al., 1992), and schizophrenia (Hamann, 2001; Herbener et al., 2007) display more preferential memory for negative cues compared to healthy controls, suggesting that memory bias for emotional over neutral stimuli can be both adaptive and maladaptive, depending on context and extent.

Like emotional cues, alcohol cues are capable of biasing attention and eliciting emotional reactions (Townshend and Duka, 2001). They also may be remembered preferentially over neutral or non-appetitive cues (Franken et al., 2003b; Klein et al., 2013). The presence of a memory bias for alcohol over neutral cues would add to a growing alcohol cue exposure literature that has shown that exposure to alcohol cues in a laboratory setting can capture subjective craving (Carter and Tiffany, 1999; Franken et al., 2003a) and reward network brain activation patterns (Heinz et al., 2004; Kambouropoulos and Staiger, 2001; Myrick et al., 2004), and predict relapse rate (Grüsser et al., 2004; Niaura et al., 1988; Sinha and Li, 2007) and pharmacological treatment outcome (Myrick et al., 2008). Understanding cognitive processes that parallel subjective, neural, and behavioral responses could further shape intervention design.

Another possible similarity between emotional and alcohol cues may be the potentiation of memory processes by state. Memory bias for emotional stimuli over neutral cues can be intensified by current, valence-parallel mood state (Fiedler and Stroebe, 1986), a process known as mood-congruent memory. For example, experimental induction of transient positive mood states facilitated better recall for positive cues (for review, see Lewis, 2003) and individuals with major depressive disorder showed greater priming and recall of negative emotional cues compared to healthy control (Bradley et al., 1995; Watkins et al., 1992). In parallel to mood congruency, it could be argued that state congruency exists when

an individual views alcohol cues during acute alcohol intoxication, such that memory for alcohol-related cues would be potentiated and memory bias for alcohol over neutral cues would be exaggerated during intoxication compared to a non-intoxicated state. The effect of alcohol consumption on state-*dependent* memory (i.e., retrieval of memory for stimuli learned under the same environmental condition) has been widely studied, but the role of alcohol consumption in state-*congruent* memory (i.e., when stimuli and state are parallel) has not been well delineated. Such alcohol-induced state-congruent memory intensification could contribute to escalations in trajectories of alcohol use behaviors.

This study examined explicit (i.e., free recall) and implicit (i.e., repetition priming) memory for picture cues that were either alcohol-related, emotionally positive, emotionally negative, or neutral. Explicit memory requires attention and conscious awareness, such as deliberate and effortful recall of past events. Implicit memory, on the other hand, refers to memory processes that proceed without conscious awareness and make few demands on attention or other cognitive resources (Dew and Cabeza, 2011; Schacter and Tulving, 1994; Schacter et al., 2007). Implicit memory processing is observable in experiments that do not include explicit instructions for memory performance, such as repetition priming, wherein reactions to previous viewed and new stimuli are compared while participants are instructed to engage in an unrelated task (i.e., sorting stimuli based on the presence or absence of image distortion). In this study, explicit and implicit memory processes were examined across groups of young adult drinkers without alcohol use disorder who either were given an active dose of alcohol (alcohol condition, target blood alcohol concentration of 0.08 mg/dl), an inactive dose of alcohol (placebo condition), or a beverage that contained no alcohol (control condition).

Our hypotheses were three-fold. First, we expected a memory bias for alcohol cues over neutral cues based on the expected parallels in salience between alcohol-related and emotional stimuli (Alkana and Parker, 1979; Bruce and Pihl, 1997; Knowles and Duka, 2004; Ray et al., 2012) and potential parallels between memory bias and attentional bias, which has been often found in drinkers (Field and Cox, 2008; Field et al., 2004). We specifically hypothesized greater explicit and implicit memory processing for alcohol cues compared to neutral cues in all beverage conditions. Second, we expected a disruption of explicit but not implicit memory processing during alcohol intoxication in line with prior studies that have shown global impairment of recall (Birnbaum et al., 1978; Goodwin et al., 1969; Soderlund et al., 2005) but intact implicit memory processing (Fillmore et al., 1999; Hayes et al., 2012; Ray and Bates, 2006; Ray et al., 2004) for neutral and emotionally-valenced cues during acute intoxication. Third, we explored whether there was state congruent memory processing for the alcohol cues in the alcohol beverage condition by assessing beverage condition x cue type interactions on explicit and implicit memory performance.

2. MATERIAL AND METHODS

2.1. Participants

One-hundred sixty-one volunteers (84 women) between the ages of 21 and 24 ($M = 21.6$, $SD = 0.8$) were recruited through advertisements in university periodicals and bulletin boards as

part of a larger study of family history, emotion, memory, and alcohol (Table 1). Participants reported their race as Asian (18%), Black, or African American (11%), White (64%), or Other (8%); Hispanic origin ethnicity was reported by 19% of participants. Ninety-six percent were current college students. Exclusion criteria were a self-reported history of a childhood learning disability, special education, psychiatric or neurological disorder, treatment for a substance use disorder, and lifetime maternal substance use disorder (to rule out prenatal alcohol exposure effects), primary language other than English, medical conditions that interact with alcohol administration, current alcohol dependence, regular (weekly) illicit or prescription drug use, and, for women, planned or current pregnancy. Due to the drinking requirements of the study, also excluded were those who were 20% over- or under-weight (adjusted for gender, height, and body frame) based on the Metropolitan Life Height-Weight Table (1983) or reported drinking of less than four drinks (men) or three drinks (women) at least twice per month in the past year. Eligibility was ascertained initially during a telephone screening interview. At the beginning of the laboratory session, weight and pregnancy status were confirmed, and standardized self-report measures of alcohol and drug use and related problems were completed.

2.2. Procedure

Eligibility was initially ascertained during a telephone screening interview. Upon arrival at the laboratory, further eligibility information was obtained. This information included photo identification to verify age; breath alcohol concentration, oral temperature, and resting blood pressure to confirm the absence of alcohol, fever, and hypertension, respectively; weight and height measurements to verify self-reported values; and a urine pregnancy test to female participants to confirm a negative pregnancy status. In addition, participants completed a 30-minute battery that included standardized self-report measures of alcohol and drug use (heavy episodic drinking occasions, typical quantity, and frequency in the past 30 days) and related problems (Brief Michigan Alcohol Screening Test [B-MAST]; Chan et al., 1994). To be eligible, participants could not self-report alcohol or other drug use within the past 24 hours or score 4 or greater on the B-MAST (i.e., present with greater than a low likelihood of alcohol dependence). As well, average alcohol quantity and frequency information needed to be consistent with that verbally reported in the telephone screening interview. All participants scheduled for a laboratory session were eligible according to these criteria and completed the study.

This study was approved by the Rutgers University Institutional Review Board for the Protection of Human Subjects Involved in Research and all participants provided written informed consent. All participants were asked to refrain from alcohol and other drug use (except caffeine and nicotine) for 24 hours and eat a light meal no sooner than 3 hours prior to arrival. Upon arrival at the laboratory, each participant was randomly assigned to complete two of the three beverage conditions in separate 3.5 hour laboratory sessions. Data from the first session were used in this study in order to avoid learning effects. After completing the self-report battery, participants were seated in a comfortable chair in front of a TV screen in a sound-attenuated, dimly lit testing room. Physiological sensors were attached to collect data for a different element of the study. Resting state was measured using a standardized, low-demand cognitive task for 5 min (Jennings et al., 1992), wherein

they silently counted the number of blue rectangles shown on a television screen. Based on their random assignment, participants then consumed one of three beverages of equivalent volume: 100% orange, cranberry, and lime juice mixer (control/told-no-alcohol condition), mixer with 100µl ethanol float per each cup and other olfactory alcohol cues (placebo condition), or mixer plus 95% ethanol dose (alcohol condition). Alcohol beverages consisted of alcohol mixed in a ratio of 4 parts mixer to 1 part ethanol; doses were calculated based on weight and gender (.90 ml/kg for men, .75 ml/kg for women) to achieve a target blood alcohol concentration (BAC) near the legal limit of intoxication for driving in the U.S. (80 mg/dl). These doses are consistent with intoxication levels commonly achieved by college-aged drinkers (Kraus et al., 2005). The beverage was divided into three equal volume drinks that the participant consumed evenly during consecutive 5-min intervals for a total of 15 min of beverage consumption. Participants in the alcohol ($n = 78$) and placebo ($n = 48$) groups were told that they would receive some amount of alcohol, whereas those in the control group ($n = 41$) were told that they would not receive alcohol.

When a BAC of ~60 mg/dl was reached on the ascending limb of the BAC curve (or after 10 min in placebo and control conditions), participants performed the resting state task again, followed by picture cue exposure. The mean BAC of participants in the alcohol group at the beginning of the cue exposure phase was 74 mg/dl (SD = 13 mg/dl) and participants were on the ascending limb of the blood alcohol curve.

2.3. Picture cue exposure

Participants viewed pictures from four categories: emotionally negative, positive, and neutral pictures, and alcohol-related pictures. Each category of pictures (i.e., picture cue block) contained a set of 15 unique pictures that was presented twice; thus, each participant saw a total of 120 cues (60 unique pictures). Emotional pictures were from the International Affective Picture System (IAPS; Lang et al., 1999). Based on the IAPS standardized ratings, negative and positive pictures were matched on the ratings of arousal, but varied systematically in valence. Neutral picture cues were of moderate valence and low arousal. Alcohol-related picture stimuli were from the Normative Appetitive Picture System (NAPS; Stritzke et al., 2004), as well as from Tapert and colleagues (2003), with additional alcohol-related pictures developed in our lab (Mun et al., 2008).

Stimulus cues were presented using E-prime software (Psychology Software Tools, Inc.). Presentation order of pictures within sets was randomized. Presentation order of cue exposure tasks was counterbalanced across participants using 24 patterns of task orders generated with SAS Proc Plan (SAS/STAT 9.3, SAS Institute, Cary, NC). Each picture was presented for 5-s with a 5-s inter-picture interval (blank screen). During the inter-picture interval, participants verbally provided either a valence or arousal rating (counterbalanced) for each picture cue using a 9-point Self-Assessment Manikin (Bradley and Lang, 1994). Verbal responses were coded and averaged across pictures in each cue block. Arousal was rated on a scale of 1 = calm or relaxed to 9 = excited, jittery, or awake. Liking/valence was rated on a scale of 1 = very negative to 9 = very positive. Each cue block lasted for 5 min, with a 30-s inter-block interval.

2.4 Memory tests

The free recall task started approximately 10 min after the picture cue learning phase ended, during which time physiological sensors (in place for the psychophysiological element of the study; completed as a part of a different study) were removed and participants took a break to go to the restroom or stretch their legs. Participants were given 10 min to verbally recall, one at a time and in detail, as many picture cues as possible from the series of pictures seen during the learning phase. Two independent raters determined whether the description of the picture cue represented a correctly recalled picture. In order to be identified as correct, all of the recalled content information had to be accurate and the picture had to be identifiable on the basis of the description (Knowles and Duka, 2004). The mean BAC of participants in the alcohol group at the beginning of the free recall task was 70 mg/dl ($SD = 13$ mg/dl) and participants were on the descending limb of the blood alcohol curve.

The repetition priming task was administered next, approximately 25 min after the completion of picture cue learning phase. We previously showed that repetition priming is not contaminated by a prior free recall task that involved the same stimulus cues (Ray and Bates, 2006). In this task, participants were explicitly asked to give ‘picture/non-picture’ decisions for each of 240 items presented sequentially in random order. Picture/nonpicture decisions were based on whether the picture contained a “real” (natural appearing) picture or contained distorted forms that would not be encountered in real life. These decisions made little demand on participants to think about the cue content (i.e., alcohol or emotional elements), per se. Importantly, these picture/non-picture decisions, were not the target of this task; rather, implicit processing was measured from reaction times to the pictures as described below. Of the 240 cues presented, 60 were pictures that had been viewed previously (15 unique pictures from each category), 60 were new pictures that had not previously viewed (15 from each of the same 4 categories), and 120 were ‘non-pictures’ that had been created by electronically distorting pictures that were not used in the experiment. Each stimulus was presented for 10 seconds and participants were asked to indicate their ‘picture/non-picture’ decision for each stimulus as quickly and accurately as possible by making one of two keyboard responses. Reaction time and accuracy data were collected. Priming is defined as the difference in reaction time to previously viewed pictures versus reaction time to new pictures; reaction time to non-pictures was not analyzed. The mean BAC of participants in the alcohol condition at the beginning of the repetition priming task was 66 mg/dl ($SD = 13$ mg/dl).

Prior to leaving the lab, participants were asked to rate their perceived level of intoxication during the experiment on a scale of 1 = “Not at all” to 7 = “Moderately Intoxicated”. Participants in the alcohol condition subjectively reported an average intoxication rating of 4.59, ($SD = 1.34$), whereas those in the placebo condition reported a mean intoxication of 2.61 ($SD = 1.22$), and the control condition did not give rise to any subjective reports of intoxication ($M = 1.00$, $SD = 0.00$).

2.5. Data analysis

Two mixed linear model (Proc Mixed) analyses (SAS/STAT 9.3, SAS Institute, Cary, NC) were conducted to examine the effects of alcohol intoxication (three between-subjects

beverage conditions: alcohol, placebo, and control), picture cue type (four within-subject repeated measures: negative, positive, neutral, alcohol-related), and their interaction on free recall and repetition priming of picture cues. For free recall, the dependent variable was the total number of picture cues accurately recalled per picture cue block. For the repetition priming task, the dependent variable was the difference between mean reaction time to previously viewed picture cues and mean reaction time to new picture cues, calculated separately for each of the four cue blocks (Burgund et al., 2003; Carlesimo, 1994; Horner and Henson, 2009; Joordens and Becker, 1997; Ober et al., 1991); higher difference scores imply greater priming. Reaction times to the “non-pictures” were not included in analyses. Reaction times that were > 5000 ms (3.5%) were removed from analyses. The subsequent range of reaction times was 197 ms – 4996 ms. On average, the response error rate was 8.8%; incorrect response trials were excluded from analyses. Effect size was estimated using Cohen’s *d* (Lakens, 2013); Cohen’s *ds* for main effects with greater than two groups were calculated using groups with the largest and smallest means. The Tukey post hoc test was used to examine the significance of pairwise differences for significant main effects. Correlations were also performed to assess the magnitude of the relationship of memory task performance to self-reported alcohol use behaviors and self-reported arousal to alcohol cues. In the alcohol use analyses, the influence of sex was partialled out due to significant sex differences in alcohol consumption.

3. RESULTS

There was a significant main effect of picture cue type on free recall, $F(3, 462) = 33.82, p < .0001, d = .22$ (Figure 1). A greater number of alcohol-related cues as well as positive and negative emotional cues were recalled compared to neutral picture cues (alcohol vs. neutral picture cues, $t(462) = 6.55, p < .0001, d = .49$; positive vs. neutral picture cues, $t(462) = -7.88, p < .0001, d = .74$; negative vs. neutral picture cues, $t(462) = 9.31, p < .0001, d = .22$). Compared to alcohol-related cues, a greater number of negative, but not positive, emotional cues were recalled (positive vs. alcohol picture cues, $t(462) = -1.33, p = n.s.$; negative vs. alcohol picture cues, $t(462) = -2.76, p < .05, d = .22$). There was also a significant main effect of beverage condition on recall, $F(2, 154) = 36.89, p < .0001, d = .85$ (Figure 1); individuals in the alcohol condition recalled significantly fewer pictures than those in the control and placebo conditions ($ps < .05$). Differences in recall between those who received control and placebo beverages were not statistically significant. There was no significant interaction effect between picture cue type and beverage condition on free recall, $F(6, 462) = 1.05, p = n.s.$, suggesting that acute alcohol intoxication globally impaired explicit memory of all picture cue types.

There was a significant main effect of picture cue type on repetition priming, $F(3, 466) = 12.63, p < .0001, d = .49$ (Figure 2). Participants showed significantly more repetition priming by alcohol-related picture cues as well as by positive and negative emotional cues compared to neutral picture cues (alcohol vs. neutral picture cues, $t(466) = 2.67, p < .05, d = .31$; positive vs. neutral picture cues, $t(466) = -3.95, p < .001, d = .42$; negative vs. neutral picture cues, $t(466) = 6.00, p < .0001, d = .49$). Compared to alcohol-related picture cues, participants exhibited significantly more repetition priming by negative, but not positive, emotional picture cues (positive vs. alcohol, $t(466) = -1.28, n.s.$; negative vs. alcohol, $t(466)$

$= -3.32, p < .01, d = .26$). There was no significant main effect of beverage condition on priming, $F(2, 156) = 1.00, p = n.s.$ (Figure 2), nor was there a significant picture cue type by beverage condition interaction, $F(6, 477) = .80, p = n.s.$

Past year frequency of alcohol use behaviors, duration of alcohol use, and alcohol-related problems were not significantly correlated with priming or recall of alcohol cues (Table 2). To assess that the cue paradigm was successful in generating sufficient emotional reactions, we characterized subjective arousal to cues. Similar to normative IAPS ratings (Lang et al., 1999), participants in this study self-reported significantly lower arousal ratings for neutral cues (2.69 ± 1.20) than for alcohol (3.76 ± 1.62), negative emotional (5.66 ± 1.64), and positive emotional (4.72 ± 1.43) picture cues. Liking/valence ratings of neutral cues suggested that these cues were subjectively experienced as neutral (4.83 ± 0.62 ; 4 = “neutral”); whereas alcohol (5.57 ± 1.04) and positive (6.60 ± 0.77) cues were experienced as positive and negative pictures (1.93 ± 0.85) were experienced as negative. Beverage condition did not significantly affect subjective arousal or valence scores. Subjective ratings of arousal and valence to the alcohol picture cues were unrelated to priming or recall of the alcohol cues (Table 2).

4. DISCUSSION

The present paper examined how alcohol cues are remembered by young adult drinkers following administration of an active dose of alcohol versus control (given no alcohol and told they would receive no alcohol) or placebo (inactive alcohol dose plus visual and olfactory cues suggestive of alcohol). The first hypothesis was confirmed; alcohol cues were preferentially retained over neutral cues. Alcohol picture cues, compared to neutral picture cues, preferentially engaged more effortful and unintentional memory processing in young adult drinkers. This memory bias for alcohol over neutral cues was on par with that seen for positive emotional over neutral cues, which paralleled the subjective rating scores that showed participants viewed alcohol cues as more arousing and more positively-valenced than neutral cues. The second hypothesis examined the impact of acute alcohol intoxication on memory. In replication of prior studies, acute alcohol intoxication resulted in a significant reduction in free recall of neutral and emotional picture cues, but had no effect on repetition priming (Lister et al., 1991; Ray et al., 2012; Soderlund et al., 2005; Tracy and Bates, 1999). We extend these findings by showing that acute intoxication also reduced free recall of alcohol picture cues, without interrupting repetition priming. The third exploratory aim focused on alcohol-specific state-congruent memory. The idea that recall and repetition priming would be enhanced for alcohol cues compared to neutral cues under alcohol intoxication was not supported.

Prior studies have demonstrated that alcohol cues compared to neutral cues are capable of biasing both attention (Townshend and Duka, 2001) and explicit memory (Franken et al., 2003a; Klein et al., 2013). To this, the present study adds evidence that alcohol cues compared to neutral cues bias implicit (repetition priming) as well as explicit (recall) memory processing. The incentive-sensitization theory (Robinson and Berridge, 1993; Vanderschuren and Pierce, 2010) suggests that, through classical conditioning, repeated episodes of alcohol consumption increase attention to formerly neutral cues such that they

take on enhanced meaning and relevance and thus draw attentional resources away from other stimuli. The present results suggest that memory for alcohol-related cues has become both consciously and automatically prioritized in young adult drinkers, most likely through repeated experiential pairings.

Attention biases have been found to be greater in heavier compared to lighter drinkers (Weafer and Fillmore, 2013) and to play an important role in the maintenance of alcohol-use and -seeking behaviors (e.g., Bauer and Cox, 1998; Johnsen et al., 1994; Robinson and Berridge, 1993; Stormark et al., 2000; Townshend and Duka, 2001; Weafer and Fillmore, 2013). Recall bias was also greater in an alcohol dependent sample compared to a light drinking control (Franken et al., 2003a). These findings are consistent with the theory that learned associations become stronger as an individual's drinking history progresses. It has been hypothesized that, over time, these associations become automatic and thus contribute to the maintenance of alcohol use behaviors, craving (Franken et al., 2003b), and drinking reinstatement after a period of abstinence (Cox et al., 2002). Even in the present non-dependent young adult drinking sample, implicit memory biases for alcohol related visual cues were already evident.

Implicit memory biases have received significant research and clinical attention as they can occur without conscious awareness and be difficult to control or inhibit once initiated (Roediger, 1990). Most research suggests that implicit cognitions precipitate alcohol use unintentionally (Ostafin et al., 2014; Thush and Wiers, 2007), even when conscious intentions are to abstain. The present study, which tested only non-dependent, young adult drinkers, provides preliminary evidence suggesting that implicit memory systems may play an important role in earlier stages of transitions in alcohol use patterns, such as occasional use to regular and/or escalating use. Because non-drinkers and individuals with symptoms of dependence were excluded (due to the study's alcohol administration design elements), the link between memory bias and initiation of use/development of disorders could not be addressed. Nonetheless, among this non-dependent, albeit at risk, sample of young adult drinkers (Table 1; Johnston et al., 2015a), memory biases may play an important role in the assessment of, or outcome from, the assignment of salience and subjective positive value to alcohol-related cues.

The observation that alcohol intoxication did not enhance recall or priming of alcohol cues is noteworthy. If state-congruent memory processes had been in place, enhanced memory for alcohol cues should have been seen. It could be argued that alcohol cue presentation during intoxication represents a multi-modal cue condition wherein physiological intoxication as well as visual stimuli serve as cues. Further, intoxication may enhance the salience or value of the picture cues as might be expected from a recent behavioral economics study showing that consumption of an intoxicating dose of alcohol compared to non-alcohol beverages increased willingness to pay higher prices for alcohol and drink more (Amlung et al., 2015). That this was not seen may further support the theory that memory for alcohol cues in non-dependent young adults may be driven in large part by the drinking culture common at U.S. universities (Johnston et al., 2015b) and the related general outlook on drinking by American college students. This speculation, however, requires formal testing by comparing memory bias for alcohol over neutral cues in college drinkers to non-drinkers, individuals

with alcohol use disorders, and samples of different ages who likely have different sociocultural associations with drinking.

There are several limitations to this study that are noteworthy. As noted above, the sample consisted of predominantly college student drinkers and thus our results may not generalize to other age or demographic groups. The fact that alcohol cues were recalled and primed on par with positive emotional cues but less than negative emotional cues may also reflect the drinking histories of the present sample. Among individuals with an alcohol use disorder or those who have experienced substantial negative consequences from use, this may not be observed. A useful future research direction would be to examine how memory facilitation for alcohol cues compared to emotional cues maps onto alcohol use experiences and expectancies, links with attention allocation and physiological arousal, and potentially varies across different longitudinal trajectories of drinking behaviors. The memory assessment in the current study did not differentiate between alcohol effects on encoding and retrieval memory processes because beverage consumption occurred prior to cue exposure. Alcohol consumption after cue exposure may enhance recall memory, often called retrograde facilitation (Bruce and Pihl, 1997; Molnar et al., 2010), but this was not tested herein. Examination of complex cognitions and behaviors related to alcohol use in a controlled laboratory setting may decrease the ecological value of the study. The experimental design used static picture cues rather than multi-modal stimuli and did not allow for realistic mimicry of important environmental and social contexts that may play an important role, such as peers, smell, taste, and ambience. While viewing alcohol pictures during intoxication may have served as a multi-modal stimulus condition; this state congruency did not affect recall or repetition priming. While the picture cue stimuli used in this study were standardized and appropriate for a controlled experimental study, they do not fully capture the dynamic and complicated environmental and social interactions that individuals face outside the laboratory. In terms of the alcohol cues, this may be particularly relevant as personal experiences, preferences, and associations with alcohol can be highly individualized and thus the alcohol cues may have been more salient to some participants than others. To minimize this, the cues included multiple alcoholic beverage types and drinking-related situations, including those most often reported in college-aged drinking samples. Future studies may benefit from examining the explicit and implicit memory biases in a more impaired sample of drinkers, such as those who meet diagnostic criteria for alcohol use disorder, individuals concomitantly undergoing acute stress, or using more ecological valid settings. Finally, it is possible that memory bias for emotional and alcohol cues could have been enhanced by greater interrelatedness of these cue types compared to neutral cues (for review, see Bennion et al., 2013).

Despite these caveats, the findings extend the prior cue reactivity literature to include the domain of memory bias by showing that alcohol cues were more often recalled and gave rise to more repetition priming than did neutral cues, even relatively early in individual alcohol use histories and prior to evidence for alcohol dependence. Thus, while alcohol intoxication impacts explicit memory processing while leaving implicit memory processing intact, exposure to alcohol-related pictures invoked more memory processing across both the effortful and automatic memory domains. In other words, even without engaging attention, alcohol cues in the environment may be capable of affecting cognitive systems.

Acknowledgments

This study was supported by funding from the National Institute on Alcohol Abuse and Alcoholism Grants R01AA015248, K02AA00325, K24 AA021778, K01AA017473, and contract HHSN275201000003C, and from the National Institute on Drug Abuse Grant K01DA029047. The authors would like to thank the study participants and research staff for making this work possible.

References

- Alkana R, Parker ES. Memory facilitation by post-training injection of ethanol. *Psychopharmacology*. 1979; 66:117–119. [PubMed: 119253]
- Amlung M, McCarty KN, Morris DH, Tsai CL, McCarthy DM. Increased behavioral economic demand and craving for alcohol following a laboratory alcohol challenge. *Addiction* (Abingdon, England). 2015; 110:1421–1428.
- Bauer D, Cox WM. Alcohol-related words are distracting to both alcohol abusers and non-abusers in the Stroop colour-naming task. *Addiction* (Abingdon, England). 1998; 93:1539–1542.
- Bennion KA, Ford JH, Murray BD, Kensinger EA. Oversimplification in the study of emotional memory. *J Int Neuropsychol Soc*. 2013; 19:953–961. [PubMed: 24007950]
- Berntsen D, Rubin DC. Emotionally charged autobiographical memories across the life span: the recall of happy, sad, traumatic, and involuntary memories. *Psychol Aging*. 2002; 17:636–652. [PubMed: 12507360]
- Birnbaum IM, Parker ES, Hartley JT, Noble EP. Alcohol and memory: retrieval processes. *J Verbal Learning Verbal Behav*. 1978; 17:325–335.
- Bradley BP, Mogg K, Williams R. Implicit and explicit memory for emotion-congruent information in clinical depression and anxiety. *Behav Res Ther*. 1995; 33:755–770. [PubMed: 7677713]
- Bradley MM, Lang PJ. Measuring emotion: the Self-Assessment Manikin and the Semantic Differential. *J Behav Ther Exp Psychiatry*. 1994; 25:49–59. [PubMed: 7962581]
- Brewin CR. A cognitive neuroscience account of posttraumatic stress disorder and its treatment. *Behav Res Ther*. 2001; 39:373–393. [PubMed: 11280338]
- Bruce KR, Pihl RO. Forget “drinking to forget”: enhanced consolidation of emotionally charged memory by alcohol. *Exp Clin Psychopharmacol*. 1997; 5:242–250. [PubMed: 9260071]
- Burgund ED, Marsolek CJ, Luciana M. Serotonin levels influence patterns of repetition priming. *Neuropsychology*. 2003; 17:161–170. [PubMed: 12597085]
- Cahill L, McGaugh JL. A novel demonstration of enhanced memory associated with emotional arousal. *Conscious Cogn*. 1995; 4:410–421. [PubMed: 8750416]
- Cahill L, McGaugh JL. Modulation of memory storage. *Curr Opin Neurobiol*. 1996; 6:237–242. [PubMed: 8725966]
- Carlesimo GA. Perceptual and conceptual priming in amnesic and alcoholic patients. *Neuropsychologia*. 1994; 32:903–921. [PubMed: 7969866]
- Carter BL, Tiffany ST. Meta-analysis of cue-reactivity in addiction research. *Addiction* (Abingdon, England). 1999; 94:327–340.
- Chan AW, Pristach EA, Welte JW. Detection of alcoholism in three populations by the Brief-Mast. *Alcohol Clin Exp Res*. 1994; 18:695–701. [PubMed: 7943678]
- Christianson, S-A. Remembering Emotional Events: Potential Mechanisms. In: Christianson, S-A., editor. *The Handbook Of Emotion And Memory: Research And Theory*. Erlbaum and Associates; Hillsdale, NJ: 1992. p. 307-340.
- Cox WM, Hogan LM, Kristian MR, Race JH. Alcohol attentional bias as a predictor of alcohol abusers’ treatment outcome. *Drug Alcohol Depend*. 2002; 68:237–243. [PubMed: 12393218]
- Ehlers A, Clark DM. A cognitive model of posttraumatic stress disorder. *Behav Res Ther*. 2000; 38:319–345. [PubMed: 10761279]
- Fiedler K, Stroehm W. What kind of mood influences what kind of memory: the role of arousal and information structure. *Mem Cognit*. 1986; 14:181–188.
- Field M, Cox WM. Attentional bias in addictive behaviors: a review of its development, causes, and consequences. *Drug Alcohol Depend*. 2008; 97:1–20. [PubMed: 18479844]

- Field M, Mogg K, Zetteler J, Bradley BP. Attentional biases for alcohol cues in heavy and light social drinkers: the roles of initial orienting and maintained attention. *Psychopharmacology*. 2004; 176:88–93. [PubMed: 15071718]
- Fillmore MT, Vogel-Sprott M, Gavrilescu D. Alcohol effects on intentional behavior: dissociating controlled and automatic influences. *Exp Clin Psychopharmacol*. 1999; 7:372–378. [PubMed: 10609972]
- Franken IA, Rosso M, van Honk J. Selective memory for alcohol cues in alcoholics and its relation to craving. *Cognit Ther Res*. 2003a; 27:481–488.
- Franken IA, Rosso M, van Honk J. Selective memory for alcohol cues in alcoholics and its relation to craving. *Cogn Ther Res*. 2003b; 27:481–488.
- Goodwin DW, Powell B, Bremer D, Hoine H, Stern J. Alcohol and recall: state-dependent effects in man. *Science*. 1969; 163:1358–1360. [PubMed: 5774177]
- Grüsser SM, Wrase J, Klein S, Hermann D, Smolka MN, Ruf M, Weber-Fahr W, Flor H, Mann K, Braus DF. Cue-induced activation of the striatum and medial prefrontal cortex is associated with subsequent relapse in abstinent alcoholics. *Psychopharmacology*. 2004; 175:296–302. [PubMed: 15127179]
- Hamann S. Cognitive and neural mechanisms of emotional memory. *Trends Cogn Sci*. 2001; 5:394–400. [PubMed: 11520704]
- Hayes SM, Fortier CB, Levine A, Milberg WP, McGlinchey R. Implicit memory in korsakoff's syndrome: a review of procedural learning and priming studies. *Neuropsychol Rev*. 2012; 22:132–153. [PubMed: 22592661]
- Heinz A, Siessmeier T, Wrase J, Hermann D, Klein S, Grüsser-Sinopoli SM, Flor H, Braus DF, Buchholz HG, Gründer G. Correlation between dopamine D2 receptors in the ventral striatum and central processing of alcohol cues and craving. *Am J Psychiatry*. 2004; 161:1783–1789. [PubMed: 15465974]
- Herbener ES, Rosen C, Khine T, Sweeney JA. Failure of positive but not negative emotional valence to enhance memory in schizophrenia. *J Abnorm Psychol*. 2007; 116:43. [PubMed: 17324015]
- Horner AJ, Henson RN. Bindings between stimuli and multiple response codes dominate long-lag repetition priming in speeded classification tasks. *J Exp Psychol Hum Learn*. 2009; 35:757–779.
- Jennings JR, Kamarck T, Stewart C, Eddy M, Johnson P. Alternate cardiovascular baseline assessment techniques: vanilla or resting baseline. *Psychophysiology*. 1992; 29:742–750. [PubMed: 1461961]
- Johnsen BH, Laberg JC, Cox WM, Vaksdal A, Hugdahl K. Alcoholic subjects' attentional bias in the processing of alcohol-related words. *Psychol Addict Behav*. 1994; 8:111.
- Johnston, LD.; O'Malley, PM.; Bachman, JG.; Schulenberg, JE.; Miech, RA. 2014 Volume 2: College Students and Adults Ages 19–55. Institute for Social Research, The University of Michigan; Ann Arbor: 2015a.
- Johnston, LD.; O'Malley, PM.; Miech, RA.; Bachman, JG.; Schulenberg, JE. 2014 Overview: Key Findings on Adolescent Drug Use. Institute for Social Research, The University of Michigan; Ann Arbor: 2015b.
- Joordens S, Becker S. The long and short of semantic priming effects in lexical decision. *J Exp Psychol Hum Learn*. 1997; 23:1083–1105.
- Kambouropoulos N, Staiger PK. The influence of sensitivity to reward on reactivity to alcohol-related cues. *Addiction (Abingdon, England)*. 2001; 96:1175–1185.
- Klein AA, Nelson LM, Anker JJ. Attention and recognition memory bias for alcohol-related stimuli among alcohol-dependent patients attending residential treatment. *Addict Behav*. 2013; 38:1687–1690. [PubMed: 23254219]
- Knowles SK, Duka T. Does alcohol affect memory for emotional and non-emotional experiences in different ways? *Behav Pharmacol*. 2004; 15:111–121. [PubMed: 15096911]
- Kraus CL, Salazar NC, Mitchell JR, Florin WD, Guenther B, Brady D, Swartzwelder SH, White AM. Inconsistencies between actual and estimated blood alcohol concentrations in a field study of college students: do students really know how much they drink? *Alcohol Clin Exp Res*. 2005; 29:1672–1676. [PubMed: 16205367]
- LaBar KS, Cabeza R. Cognitive neuroscience of emotional memory. *Nat Rev Neurosci*. 2006; 7:54–64. [PubMed: 16371950]

- Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol.* 2013; 4:863. [PubMed: 24324449]
- Lang, PJ.; Bradley, MM.; Cuthbert, BN. International Affective Picture System (IAPS): Technical Manual And Affective Ratings. The Center For Research In Psychophysiology, University of Florida; Gainesville, FL: 1999.
- Lewis PA, Critchley HD. Mood-dependent memory. *Trends Cogn Sci.* 2003; 7:431–433. [PubMed: 14550485]
- Lister RG, Gorenstein C, Risher-Flowers D, Weingartner HJ, Eckardt MJ. Dissociation of the acute effects of alcohol on implicit and explicit memory processes. *Neuropsychologia.* 1991; 29:1205–1212. [PubMed: 1791932]
- Molnar M, Boha R, Czigler B, Gaal ZA. The acute effect of alcohol on various memory processes. *J Psychophysiol.* 2010; 24:249–252.
- Mun EY, von Eye A, Bates ME, Vaschillo EG. Finding groups using model-based cluster analysis: heterogeneous emotional self-regulatory processes and heavy alcohol use risk. *Dev Psychol.* 2008; 44:481. [PubMed: 18331138]
- Myrick H, Anton RF, Li X, Henderson S, Drobos D, Voronin K, George MS. Differential brain activity in alcoholics and social drinkers to alcohol cues: relationship to craving. *Neuropsychopharmacology.* 2004; 29:393. [PubMed: 14679386]
- Myrick H, Anton RF, Li X, Henderson S, Randall PK, Voronin K. Effect of naltrexone and ondansetron on alcohol cue-induced activation of the ventral striatum in alcohol-dependent people. *Arch Gen Psychiatry.* 2008; 65:466–475. [PubMed: 18391135]
- Niaura RS, Rohsenow DJ, Binkoff JA, Monti PM, Pedraza M, Abrams DB. Relevance of cue reactivity to understanding alcohol and smoking relapse. *J Abnorm Psychol.* 1988; 97:133. [PubMed: 3290304]
- Ober BA, Shenaut GK, Jagust WJ, Stillman RC. Automatic semantic priming with various category relations in Alzheimer's disease and normal aging. *Psychol Aging.* 1991; 6:647–660. [PubMed: 1777154]
- Ohman A, Mineka S. Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychol Rev.* 2001; 108:483–522. [PubMed: 11488376]
- Ostafin BD, Kassman KT, de Jong PJ, van Hemel-Ruiter ME. Predicting dyscontrolled drinking with implicit and explicit measures of alcohol attitude. *Drug Alcohol Depend.* 2014; 141:149–152. [PubMed: 24880693]
- Ray S, Bates ME. Acute alcohol effects on repetition priming and word recognition memory with equivalent memory cues. *Brain Cogn.* 2006; 60:118–127. [PubMed: 16377048]
- Ray S, Bates ME, Bly BM. Alcohol's dissociation of implicit and explicit memory processes: Implications of a parallel distributed processing model of semantic priming. *Exp Clin Psychopharmacol.* 2004; 12:118–125. [PubMed: 15122956]
- Ray S, Mun EY, Buckman JF, Udo T, Bates ME. Memory for emotional picture cues during acute alcohol intoxication. *J Stud Alcohol Drugs.* 2012; 73:718–725. [PubMed: 22846235]
- Robinson TE, Berridge KC. The neural basis of drug craving: an incentive-sensitization theory of addiction. *Brain Res Brain Res Rev.* 1993; 18:247–291. [PubMed: 8401595]
- Roediger HL 3rd. Implicit memory. Retention without remembering *Am Psychol.* 1990; 45:1043–1056. [PubMed: 2221571]
- Roosendaal B. Glucocorticoids and the regulation of memory consolidation. *Psychoneuroendocrinology.* 2000; 25:213–238. [PubMed: 10737694]
- Sinha R, Li CSR. Imaging stress-and cue-induced drug and alcohol craving: association with relapse and clinical implications. *Drug Alcohol Rev.* 2007; 26:25–31. [PubMed: 17364833]
- Soderlund H, Parker ES, Schwartz BL, Tulving E. Memory encoding and retrieval on the ascending and descending limbs of the blood alcohol concentration curve. *Psychopharmacology.* 2005; 182:305–317. [PubMed: 16160875]
- Stormark KM, Laberg JC, Nordby H, Hugdahl K. Alcoholics' selective attention to alcohol stimuli: automated processing? *J Stud Alcohol.* 2000; 61:18–23. [PubMed: 10627092]
- Stritzke WGK, Breiner MJ, Curtin JJ, Lang AR. Assessment of substance cue reactivity: advances in reliability, specificity, and validity. *Assessment.* 2004; 18:148–159.

- Tapert SF, Cheung EH, Brown GG, Frank LR, Paulus MP, Schweinsburg AD, Meloy MJ, Brown SA. Neural response to alcohol stimuli in adolescents with alcohol use disorder. *Arch Gen Psychiatry*. 2003; 60:727–735. [PubMed: 12860777]
- Thush C, Wiers RW. Explicit and implicit alcohol-related cognitions and the prediction of future drinking in adolescents. *Addict Behav*. 2007; 32:1367–1383. [PubMed: 17125932]
- Townshend J, Duka T. Attentional bias associated with alcohol cues: differences between heavy and occasional social drinkers. *Psychopharmacology*. 2001; 157:67–74. [PubMed: 11512045]
- Tracy JI, Bates ME. The selective effects of alcohol on automatic and effortful memory processes. *Neuropsychology*. 1999; 13:282–290. [PubMed: 10353377]
- Vanderschuren LJ, Pierce RC. Sensitization processes in drug addiction. *Curr Top Behav Neurosci*. 2010; 3:179–195. [PubMed: 21161753]
- Watkins PC, Mathews A, Williamson DA, Fuller RD. Mood-congruent memory in depression: emotional priming or elaboration? *J Abnorm Psychol*. 1992; 101:581. [PubMed: 1500617]
- Weafer J, Fillmore MT. Acute alcohol effects on attentional bias in heavy and moderate drinkers. *Psychol Addict Behav*. 2013; 27:32. [PubMed: 22732051]

HIGHLIGHTS

1. Alcohol but not placebo and control beverage impaired explicit memory of pictures.
2. Implicit memory of picture cues was not impaired by any of the three beverages.
3. Explicit memory was greater for alcohol and emotional compared to neutral cues.
4. Implicit memory was greater for alcohol and emotional compared to neutral cues.
5. Results extend the alcohol cue reactivity literature to include memory bias.

Figure 1.

Effect of (A) beverage condition and (B) picture cue type on free recall, a task of explicit memory processing.

There were significant main effects of alcohol beverage (alcohol, placebo, and control conditions) and picture cue type on free recall; no interaction effects were detected. Participants who received placebo and non-alcoholic beverages recalled significantly more pictures, regardless of cue type, than those in the alcohol condition. Across the beverage conditions, participants recalled more alcohol and emotional cues than neutral cues ($p < .05$). Error bars show standard errors.

Figure 2.

Effect of (A) beverage condition and (B) picture cue type on repetition priming, a task of implicit memory processing.

There was a significant main effect of picture cue type, but not beverage condition (alcohol, placebo, and control beverages), on repetition priming. No interaction effects were detected. Regardless of condition, participants showed significantly more priming by alcohol, positive, and negative pictures compared to neutral cues, and more priming by negative emotional cues compared to alcohol cues ($p < .05$). Error bars show standard errors.

Table 1

Participant alcohol use characteristics

	All participants (<i>N</i> = 161)	Men (<i>N</i> = 84)	Women (<i>N</i> = 71)
	<i>M</i> (<i>SD</i>)		
Maximum drinks past 30 days ^a	7.7 (3.2)	9.1 (8.4)	6.3 (5.7)
Average weekly drinking occasions past 30 days ^a	1.8 (1.2)	2.1 (1.8)	1.5 (1.3)
Average standard drinks per occasion past 30 days ^a	5.0 (2.1)	5.9 (5.4)	4.2 (3.8)
Average weekly drinking occasions past year ^a	1.8 (1.1)	2.0 (1.8)	1.6 (1.4)
Average standard drinks per occasion past year ^a	5.1 (1.8)	5.7 (5.2)	4.5 (3.9)
Lifetime drinking duration (in years)	4.9 (2.0)	5.0 (4.5)	4.9 (4.4)
Average BMAST score	0.3 (0.9)	0.4 (0.2)	0.3 (0.1)

Note. BMAST = Brief Michigan Alcoholism Screening Test (4 points is suggestive of alcoholism; 5 points indicates alcoholism)

^aSignificantly different between men and women, *p* < .05

Pearson's correlation coefficients (r) between memory measures and drinking behaviors and subjective cue ratings

Table 2

	Recall			Repetition Priming				
	Neutral Cues	Alcohol Cues	Positive Cues	Negative Cues	Neutral Cues	Alcohol Cues	Positive Cues	Negative Cues
Past year alcohol use frequency	.04	.03	.11	.01	.11	.11	-.06	-.02
Lifetime drinking duration	.11	.03	.15	.15	-.12	-.02	.00	-.01
Alcohol-related problems ^a	.09	.08	.04	.11	.01	-.06	-.07	-.08
Alcohol cue arousal ratings ^b		-.01				0.00		
Alcohol cue valence ratings ^b		0.11				0.09		

^a Total Brief Michigan Alcoholism Screening Test score

^b Subjective Ratings score

Note. No statistically significant correlations were detected ($p > .05$).