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A Working Memory Bias for Alcohol-Related Stimuli Depends on Drinking Score

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We tested 44 participants with respect to their working memory (WM) performance on alcohol-related versus neutral visual stimuli. Previously an alcohol attentional bias (AAB) had been reported using these stimuli, where the attention of frequent drinkers was automatically drawn toward alcohol-related items (e.g., beer bottle). The present study set out to provide evidence for an alcohol memory bias (AMB) that would persist over longer time-scales than the AAB. The WM task we used required memorizing 4 stimuli in their correct locations and a visual interference task was administered during a 4-sec delay interval. A subsequent probe required participants to indicate whether a stimulus was shown in the correct or incorrect location. For each participant we calculated a drinking score based on 3 items derived from the Alcohol Use Questionnaire, and we observed that higher scorers better remembered alcohol-related images compared with lower scorers, particularly when these were presented in their correct locations upon recall. This provides first evidence for an AMB. It is important to highlight that this effect persisted over a 4-sec delay period including a visual interference task that erased iconic memories and diverted attention away from the encoded items, thus the AMB cannot be reduced to the previously reported AAB. Our finding calls for further investigation of alcohol-related cognitive biases in WM, and we propose a preliminary model that may guide future research.

Keywords: alcohol abuse, social drinking, alcohol attentional bias (AAB), alcohol memory bias (AMB), working memory (WM)

Understanding the cognitive processes that underpin drinking decisions at all levels of alcohol consumption should go a long way to help develop reduction interventions appropriate to the different levels. Alcohol attentional bias (AAB) is one of some dozen cognitive constructs that have become a research focus during the last 25 years. AAB is defined as a bias for attention to be directed toward alcohol-related stimuli. It has been consistently reported in those who are excessive consumers of alcohol, and it is expressed behaviorally as a (selective) attention bias to alcohol-related information thought to have developed in part, at least, as a result of their consumption history (see Field & Cox, 2008, for review). The present study provides a logical extension of this phenomenon. Namely, do those who consume alcohol more frequently show an alcohol memory bias (AMB) similar to the bias that was revealed in attention (AAB)?

The robustness of AAB is reflected in the different experimental paradigms through which it has been demonstrated and across the spectrum of excessive consumption, that is, in those with alcohol dependence (Lusher, Chandler, & Ball, 2004; Stormark, Laberg, Nordby, & Hugdahl, 2000), in problem drinkers who had been diagnosed with alcohol use disorder and were in treatment (B. T. Jones, Bruce, Livingstone, & Reed, 2006; Sharma, Albery, & Cook, 2001), as well as in heavier social drinkers who were neither diagnosed nor in treatment but who scored high on alcohol consumption questionnaires (B. C. Jones, Jones, Blundell, & Bruce, 2002; B. T. Jones, Jones, Smith, & Copley, 2003; Sharma et al., 2001; Townshend & Duka, 2001).

AAB was first demonstrated with the Stroop paradigm (Johnsen, Laberg, Cox, Vaksdal, & Hugdahl, 1994), where the primary task is to quickly name the color of the print of words visually presented while ignoring the semantic context of each word. When the semantic content is alcohol-related (e.g., beer) the color-naming latency of heavier drinkers, problem drinkers, or alcoholics is found to be greater than when the semantic content is neutral (e.g., door). Corresponding control groups showed no such color-naming differences (Johnsen et al., 1994; Sharma et al., 2001). AAB is thought to be the result of the alcohol-related semantic content acting as a distracter in excessive consumers, grabbing attention resources resulting in a color-naming performance decrement.

AAB has also been explored with the dot probe paradigm (e.g., Townshend & Duka, 2001) in which pairs of stimuli are visually presented, one to the left and one to the right of a central fixation point and then followed by a dot probe in register with one of the pair. Excessive consumers are found to respond more quickly to the dot probe when it follows an alcohol-related stimulus than when it follows a neutral one (Townshend & Duka, 2001). The authors concluded that in high alcohol users attention was drawn

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toward the alcohol stimulus and was therefore already at the location of the subsequent probe, resulting in faster response times. There is a suggestion that pictorial stimuli might elicit a stronger AAB in the dot probe paradigm than textual stimuli (Townshend & Duka, 2001).

Jones et al. (2003) used a novel version of the so-called "flicker paradigm" (see Rensink, Oregan, & Clark, 1997) to investigate whether alcohol-related stimuli really "grab" attention in people with higher levels of alcohol consumption (Sobell & Sobell, 1992). Their experiment involved two complex visual scenes both with identical content, presented in continuously cycling succession, only separated by a mask. There were two critical manipulations to the second of the two cycled scenes: an alcohol-related object (a whisky bottle) and a neutral object (a videocassette holder) were turned from label-front to label-back. Cycling presentations continued until the participant spotted "the change" (it was implied that there was only one change) and it was found that those who spotted the alcohol-related change had higher consumptions than those who spotted the neutral change. In a subsequent flicker paradigm experiment Jones et al. (2003) showed that when only one change was given to be detected, heavier social drinkers spotted the change quicker when it was alcohol-related than did a lighter social drinking control group and this was not the case with the neutral change. This was replicated with problem drinkers in treatment and using slightly modified stimuli by Jones et al. (2006). Because of the general difficulties with spotting changes, the paradigm is described as inducing so-called "change blindness" (Rensink et al., 1997). Importantly, change detection eventually occurs if attention is directed to the changing location by, for example, "interests" (see Rensink et al., 1997), which in Jones et al.'s experiments represents a developed interest in alcohol-related stimuli (AAB).

Finally, using a quite different methodological approach, Ceballos, Komogortsev and Turner (2009) recorded the eye movements of university students during the presentation of alcohol-related and neutral pictures. They observed that quantity and frequency of alcohol consumption correlated positively with (1) the amount of time spent looking at alcohol-related images and (2) initial fixations on first presentation of an alcohol-related scene, that is, salience. In contrast, alcohol consumption negatively predicted time spent and initial fixations on the neutral images. In sum, these data support the argument that alcohol-related stimuli do in fact grab attention in those who excessively consume alcohol to a greater extent than those who do not. These findings corroborate theoretical notions which assume conditioning of appetitive states in relation to drug-related stimuli that sustain addictions by controlling actions and attention (Milton & Everitt, 2012; Stewart, Dewit, & Eikelboom, 1984). The AAB is particularly congruent with the theory of incentive-sensitization posited by Robinson and Berridge (2003), who proposed that excessive alcohol consumption results in neurophysiological changes that alter the neural responses to once neutral stimuli which now have salience and grab attention, thus producing an AAB.

Based on the AAB effects found in various populations of alcohol users (ranging from alcohol-dependency to heavier social drinking) as described above, the present study examines its cognitive extension: Does an AAB lead to an alcohol memory bias (AMB) at the level of "short-term" or "working" memory (WM, Baddeley, 1986)? The relationship between attention and WM is well established (for review see Miyake & Shah, 1999). In the simplest understanding, information must be attended before it can be successfully encoded into WM. For example, the "embedded-process" model (Cowan, 1999) of WM proposes that items that enter the focus of attention are activated and hence encoded more strongly than those items that are outside the focus. In this notion attention acts as a filter or gateway to memory, which has been reiterated in several other models of attention and WM (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Dehaene, Sergent, & Changeux, 2003; Oberauer, 2002). However, existing investigations of WM in social and binge drinkers have revealed mixed results at best. Some findings claim that binge drinkers have gross general impairments in memory (Brown, Tapert, Granholm, & Delis, 2000; Schweinsburg, McQueeny, Nagel, Eyler, & Tapert, 2010; Sher, Martin, Wood, & Rutledge, 1997; Tapert, Baratta, Abrantes, & Brown, 2002; Tapert & Brown, 1999; Townshend & Duka, 2005), whereas others found no impairment in WM functioning at all (Crego et al., 2010; Crego et al., 2009). For example, Crego et al. (2010) measured WM performance of binge drinkers and controls by means of abstract line figures as stimuli. No difference between groups was observed, which is not surprising in the context of the AAB: An abstract visual stimulus is unlikely to evoke a strong attentional bias to the extent that it will influence WM performance. Very few studies to date (e.g., Gladwin & Wiers, in press) have contrasted WM performance in relation to neutral versus alcohol-related stimuli in social drinkers or other drinking patterns, and none so far has aimed at establishing a link between AAB and a possible AMB by showing enhanced performance for alcohol-related stimuli in people with higher alcohol consumption.

Of major importance for the present report is Cowan's (1999) suggestion that the allocation of attention is under the joint control of automatic (salient habituation) and voluntary (central executive) processes. This distinction is of relevance to the AAB, as it was suggested that the automatic allocation of attention is influenced by "especially noticeable events" (Cowan, 1999, p. 65) such as those "stimuli with special significance to the subject" (Cowan, 1999, p.67; see also Wood & Cowan, 1995). Thus, chronic exposure to alcohol—in concordance with incentive-sensitization and appetitive conditioning—is likely to result in alcohol-related stimuli capturing attention in a relatively automatic manner. We expect that if stronger drinkers possess an AAB then this may enhance the representational strength of alcohol-related stimuli within early encoding leading to a subsequent AMB compared to weaker drinkers. Furthermore, as suggested by Yeh, Yang, and Chiu (2005), "all the features of an object receive the benefits and costs of selective attention" (p. 796). For example, it has been observed that orienting attention to a spatial location offered a WM advantage for items presented at that location compared to items presented at a different location (Awh & Jonides, 2001; Awh, Jonides, & Reuter-Lorenz, 1998; Griffin & Nobre, 2003; Makovski, Sussman, & Jiang, 2008). Therefore, we expected that focused attention on alcohol-related images would also offer an advantage to their associated features, that is, the binding of alcohol items to their originally presented locations.

To investigate this possibility the present study used a modified version of the delayed-match-to-sample task (Sternberg, 1966), similar to the paradigm in Harkin and Kessler (2009; Harkin, Rutherford & Kessler, 2011) but including a visual interference task during delayed recall adopted from Kessler and Kiefer (2005). As selective attention was necessary to resolve visual interference while maintaining the four items in short-term memory (STM), conditions were met for tapping into WM and not only STM maintenance (for details see Kessler & Kiefer, 2005). The Harkin and Kessler (2009) and Kessler and Kiefer (2005) studies engaged the so-called "episodic buffer" by using stimuli that required conjunctions between spatial locations and letters or shapes, respectively. The episodic buffer had been proposed by Baddeley (2000) to explain the manner in which the cognitive system solves the multimodal "binding problem" (Treisman, 1996), whereby information from a variety of sources (e.g., phonological, color, location, smell) is bound into a coherent single memory episode. Not only did this provide a unitary cognitive resource explaining the integration of multimodal stimuli but it also defined where and how a selective attentional bias (i.e., AAB) could provide a memory advantage to specific objects and their associated location bindings. Further, in a manner similar to that of incentive-sensitization theory it has been argued that with repeated exposure (i.e., chronic alcohol consumption) salient visual stimuli (e.g., bottle of beer) and their associated contexts (e.g., top shelf of fridge) become automatic, as the association between bindings becomes "fixed and fully determined by the existing connectivity between neurons" (Van Rullen, 2009, p.112). Thus, an AAB may not only result in a memory advantage for alcohol-related stimuli per se but also for the bindings which tie the object to its usual context, that is, a cold bottle of beer in the top shelf of the fridge. While we did not test for an AAB separately, we expected an AMB to occur as a reflection of more efficient attentive processing of alcohol-related stimuli in persons who drink more frequently. The specific aim of the present study was to engage the episodic buffer by presenting two alcohol-related and two neutral photographs in eight possible locations. These photographs were adopted from Jones et al. (2006) for which problem drinkers previously showed an AAB. Participants were required to encode the location of the four items into WM and then recall if a single item (alcohol-related or neutral) was correctly or incorrectly located. Additionally, an easy shape-discrimination task was inserted between encoding and retrieval (cf. Kessler & Kiefer, 2005) to wipe out the image pattern from the sensory buffer, which otherwise could have aided memory recall without the need for effortful encoding and multimodal binding. Such lingering visual patterns in the sensory buffer have been termed "iconic memory" (for review, see Coltheart, Laming, Routh, & Broadbent, 1983). The interference caused by the discrimination task also ensured that executive processes were engaged in addition to STM maintenance.

Finally, we investigated the existence of an AMB within the student population and their friends (see Method for details) as we reasoned that a cognitive bias might be revealed even with subtle differences in drinking patterns compared to general memory deficits being predominantly reported for clinical alcohol abuse compared to controls (for review, see Milton & Everitt, 2012). Social episodic drinking has been identified as a very common problem in Western societies, especially among adolescents and college students (Ham & Hope, 2003; Hingson, Heeren, Winter, & Wechsler, 2005; Townshend & Duka, 2002; Wechsler, Davenport, Dowdall, Moeykens, & Castillo, 1994; Wechsler et al., 2002). A great danger of such drinking patterns is that the younger male generation seems to regard it as socially acceptable (i.e., "a good night out": The Alcohol Harm Reduction Strategy, Cabinet Office, 2004). Therefore, revealing alcohol-related alterations in cognitive processing in this target group could help unravel the mechanisms of how social drinking may progress into chronic drinking patterns. Specifically, we predicted that an AMB would depend on the frequency of drinking habits resulting from the capacity of alcohol-related stimuli to grab the attention of higher scorers during WM encoding. In other words, high scorers were predicted to reveal better recall performance for locations of alcohol-related stimuli in comparison with low scorers.

Method

Participants

Fifty male participants (mean age: 23.66; all Caucasian) were recruited via the departmental website, of which 45 were undergraduate (college) students, while the remaining five were recruited from students' friends. All participants gave written informed consents and received payment or course credits for their participation. We restricted the sample to male participants for two reasons: (1) to avoid the issue of gender differences in drinking definitions and sex-specific cut-off scores (Emslie, Lewars, Batty, & Hunt, 2009; Herring, Berridge, & Thom, 2008; Wechsler, Dowdall, Davenport, & Rimm, 1995), (2) the issue of female sensitivity to the neurotoxic effects of alcohol remains unresolved (for review see Oscar-Berman & Marinkovic, 2007; Squeglia, Schweinsburg, Pulido, & Tapert, 2011). Six participants were removed because of low accuracy on the WM task (~50% indicating guessing) or largely discrepant alcohol questionnaire responding (suggesting miscomprehension or nonveridical responding).

Measures

We measured the drinking habits of our participants in concordance with a research tradition that evaluated drinking and episodic or binge drinking based on a modified version of the Alcohol Use Questionnaire (AUQ; Mehrabian & Russell, 1978), where drinking speed and frequency of getting drunk are measured as the core features of drinking habits (Cranford, McCabe, & Boyd, 2006; Stephens & Duka, 2008; Townshend & Duka, 2001, 2002, 2005). Specifically, we calculated drinking scores based on the answers given to the following three items adapted from the AUQ: "How many drinks do you have per hour on average?", "On how many occasions do you go drinking per week?", "Of these occasions how frequently are you drunk?" (see Table 1). We generated z scores for each item separately and then averaged the three z scores for each individual to obtain a single drinking score. Cronbach's alpha across the three items was .66 (avg. corr = .4), which is reasonable given the small number of items (Cortina, 1993).

Stimuli and Procedure

All procedures were in concordance with the Declaration of Helsinki and approved by the local ethics committee in concordance with British Psychological Society ethical requirements. Participants sat in front of a 19″ computer screen at 75 cm viewing distance that was maintained by means of a chin rest. Stimuli were

Table 1
Descriptive Statistics

Measures	Median	Mean	*SD* (±)	Min	Max
Drinks/hour	2	1.97	0.87	0.00	4.00
Drinking frequency/week	1	1.65	1.20	0.00	5.00
Frequency drunk when drinking	1	0.86	0.89	0.00	3.00
Drinking score: Average across 3 *z* scores	−0.12	0	0.77	−1.27	1.67
Age	21	23.66	7.25	18	44

Note. $n = 44$. Cronbach's alpha across the three items in rows 1–3 = .66 (avg. corr = .4). Row 4: "drinking score" = average across *z* scores for the three items in rows 1–3.

presented against a gray background within a 2 (rows) × 4 (columns) matrix. After 2000 ms fixation, four images (adopted from Jones et al., 2006) were presented randomly in four of the eight possible locations. Two of these images were alcohol-related (e.g., bottle of beer, whisky bottle) and two of these were neutral (e.g., coffee-pot, glass of milk), and participants had 4000 ms to encode the images and their locations (see Figure 1). During the retention interval (WM delay) a visual discrimination task was presented and required the participant to respond to a central shape on the screen and decide whether it was jagged (indicated by pressing "1" on the keyboard) or smooth (indicated by pressing "2") and were instructed to respond within 4000 ms (to keep the WM delay constant). As explained above, this served to reduce the influence of so-called "iconic memory" (for review, see Coltheart et al., 1983), where patterns lingering in the sensory buffer of the visual system could aid memory without the need for active rehearsal and other executive processes. Finally, the memory probe was presented and required participants to indicate whether the probe image was correctly positioned with respect to its originally encoded location. This image was either alcohol-related (50% of trials) or neutral (50% of trials). The probe stimulus was always part of the encoded set in terms of identity but was only correctly located in 50% of all trials. There were eight practice trials and the 80 experimental trials comprising 20 trials of alcohol stimulus at correct probe locations, 20 trials of alcohol stimulus at incorrect probe locations, 20 trials of neutral stimulus at correct probe locations, and 20 trials of neutral stimulus at incorrect probe locations.

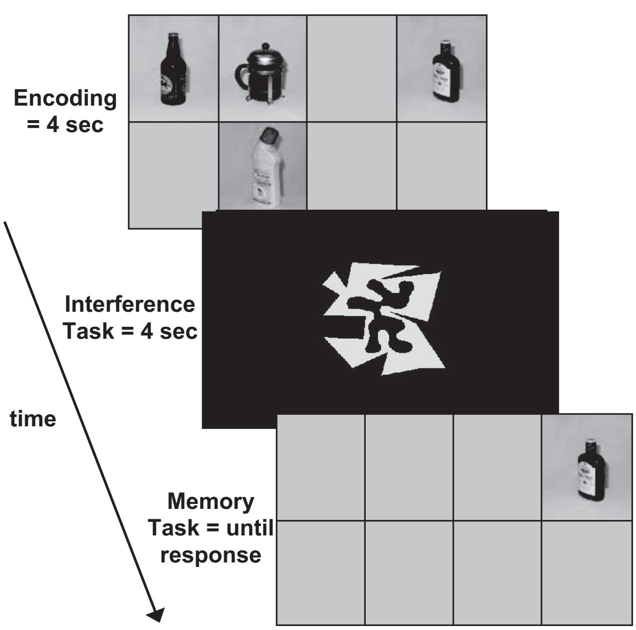

Figure 1. Schematic procedure of an example trial. An encoding set comprising two alcohol-related (bottle of beer, whisky bottle) and two neutral (coffee-pot, toilet cleaner) stimuli. An interference task in form of a visual discrimination judgment was then completed during WM delay. Finally, participants indicate whether a probe stimulus—here the whisky bottle—was correctly or incorrectly located with respect to the encoded set (here it is correctly located). Further explanations in the text.

Design

The two factors *stimulus-type* (alcohol-related vs. neutral) and *location* (correct vs. incorrect) together with the continuous predictor *drinking score* were included into two general linear model (GLM) analyses for response time (RT) and accuracy data (ACC: percentage of correct responses), respectively.

Results

Descriptive statistics are shown in Table 1 showing drinking scores obtained as the standardized average across each participant's responses to three critical items: "frequency of being drunk when drinking," "weekly drinking amount," "usual drinking speed in drinks per hour" (see Measures for details) for which means and standard deviations are also provided.

Memory Probe Response Latencies

The GLM analysis for memory probe response latencies (RTs) revealed no significant main effects or interactions (all $p > .05$). Therefore, any differences in accuracy cannot be reduced to a mere speed–accuracy trade-off.

Memory Probe Accuracy (ACC)

A GLM analysis with *drinking score* as a continuous predictor together with the within-subject factors *stimulus-type* (alcohol-related vs. neutral) and *location* (correct vs. incorrect) revealed a main effect of location, $F(1, 42) = 6.9$, $p = .012$, $\eta_p^2 = .141$, an interaction between stimulus-type × drinking-score, $F(1, 42) = 4.2$, $p = .048$, $\eta_p^2 = .09$, and an interaction between stimulus-type × location × drinking-score, $F(1, 42) = 9$, $p = .0045$, $\eta_p^2 = .177$, reached significance.

The main effect of location indicates less accuracy for correctly compared with incorrectly located images (87.8% vs. 92.7%). This pattern is congruent with previous experiments (see Exp. 1; Harkin & Kessler, 2009; Exp. 2; Harkin, Rutherford, & Kessler, 2011). Accordingly, we suggest that a correctly located memory probe requires the recall of the exact memory of the stimulus identity in its location for precise matching of probe and memory. In contrast, incorrectly located probe images can be sometimes resolved using incomplete information, such as location only. That is, if a participant merely remembered the locations where objects had been and if the probe was displayed at a previously "unoccupied" location, then the probe could be dismissed as incorrect based on location information alone without the need to consult identity information. In our paradigm the chances for an incorrect probe to appear in a previously "unoccupied" location were 4 of 7 (>50%), thus potentially favoring such a strategy. In contrast, for verifying a correctly located probe, a participant had to recall the full identity-to-location binding from memory and could not rely on location information alone (as this would only flag that location as previously "occupied").

The significant two-way interaction between drinking score and stimulus-type as well as the three-way interaction between drinking score, stimulus-type, and location suggests that accuracy for alcohol-related compared to neutral probe stimuli differed in a systematic way depending on the participants drinking habits. In addition, this pattern was only observed for probes shown in correct locations, which is in agreement with our interpretation that this was the harder condition compared with probes shown in incorrect locations. Figure 2 reveals that high scorers were more accurate for alcohol-related stimuli than low scorers and that this pattern was only observed for correct probe locations (accuracy values shown representatively at ± 1 standard deviation of drinking score). Low scorers tended to be better at processing neutral compared with alcohol stimuli. Thus, conforming to our hypothesis, high scorers are more likely to show an AMB compared with low scorers. This finding is particularly emphasized by the fact that this AMB was found in the most difficult memory condition (i.e., correctly located probes).

Discussion

We report a novel "Alcohol Memory Bias" (AMB) in a simple working memory (WM) task adapted from our previous studies (Harkin, Rutherford, & Kessler, 2011; Kessler & Kiefer, 2005) which used the same stimuli as Jones et al. (2006). The AMB was significantly related to drinking scores, and to our knowledge this is the first time that such a memory bias has been reported. The AMB occurred in the absence of a general performance difference between frequent and infrequent drinkers. The acuteness of the AMB is further underlined as it occurred in the more difficult condition when probes were correctly located (compared to incorrectly located). To reiterate, we suggested that a correctly located memory probe requires the exact memory of the probe in its encoded location so that the match between probe and memory can be accomplished. In contrast, incorrectly located probes can be completed on a substantial number of trials using only partial information, such as location information alone, for dismissing a probe as incorrect. Thus, the observed AMB reveals a memory advantage for alcohol-related stimuli in the more difficult (correct location) compared with the easier (incorrect location) condition where performance was already operating at ceiling level.

Our finding of an AMB is noteworthy as it was observed in a sample of nonclinical drinkers (see Table 1) with less pronounced drinking habits compared with the majority of the samples investigated throughout the literature. However, despite testing heavier episodic or binge drinkers, the literature is rather mixed, with some studies reporting gross memory impairments (Brown et al., 2000; Schweinsburg et al., 2010; Sher et al., 1997; Tapert et al., 2002; Tapert & Brown, 1999; Townshend & Duka, 2005) or no impair-

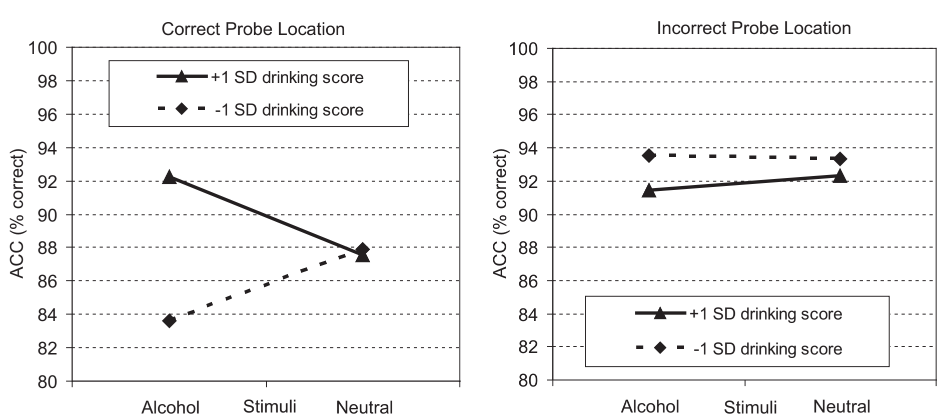

Figure 2. Interaction between "drinking score" (continuous) × "stimulus type" (alcohol vs. neutral) × "probe location" (correct vs. incorrect). The interaction with the continuous measure "drinking score" is visualized by means of estimated accuracy values for each condition at +1 *SD* and −1 *SD* of the drinking score, respectively. The accuracy values were estimated based on the GLM by using the *b* values and intercept calculated for drinking score in each condition (SPSS). Only with alcohol-related probe stimuli in correct locations (left graph, left side) a strong difference between +1 *SD* vs. −1 *SD* was observed, suggesting that higher scorers performed better with alcohol-related probes (in correct locations) than lower scorers. Higher scorers also performed better with alcohol stimuli than with neutral probes, whereas for lower scorers the reverse was true.

ment at all (Crego et al., 2010; Crego et al., 2009). For example, Crego et al. (2010) measured WM performance using abstract line figures as stimuli. No difference between drinkers and controls was observed, which is in agreement with the research presented here: An abstract visual stimulus is unlikely to evoke a strong attentional bias to the extent that it will influence WM performance. We suggest that the use of alcohol-related images may help clarify the existence or absence of WM alterations related to alcohol-abuse, particularly in population samples that comprise nonclinical drinkers, who, nevertheless, might be at risk for developing an alcohol use disorder. However, a few limitations of our study have to be noted. In addition to the small sample size, the exclusion of female participants limits the generalizability of our findings. In the light of the reported sex differences in susceptibility to intoxication and differences in cut-off scores (e.g., Emslie et al., 2009; Herring et al., 2008; Wechsler et al., 1995) it was a rational a priori decision to focus on male participants only to facilitate a first "proof of existence" of the AMB. Finally, the use of nonclinical alcohol users highlights the potential importance of the AMB in relation to casual alcohol use and the early stages of chronic alcohol abuse, however further investigations are required to shed light on how the AMB might generalize to clinically diagnosed heavy drinkers.

Overall we can conclude from our results that the episodically rich alcohol images, which had previously evoked an AAB in problem drinkers (Jones et al., 2006), have resulted in a similar alcohol-related cognitive bias during WM encoding, maintenance and/or retrieval. Jones et al. (2003) proposed that for alcohol users attention to alcohol-related stimuli is augmented. As a result, the more people drink the more likely it is that alcohol-related stimuli capture their attention automatically, resulting in the AMB presently observed. Importantly, we found systematic differences between high and low drinking scorers, although the range of scores was rather small and not within clinical range (cf. Table 1). Our pattern of results further suggests that low scorers tended to perform better for neutral compared with alcohol-related probe stimuli. We propose that less frequent exposure to alcohol-related stimuli compared with neutral stimuli, such as a coffee maker or a glass of milk, could result in richer episodic representations for neutral stimuli which are then encoded and maintained more effectively.

Although it is essential to relate the AMB to the AAB particularly during WM encoding, it is also important to highlight that the AMB cannot be reduced to an AAB, as it was observed after a 4-sec delay period including a visual interference task that erased iconic memories and diverted attention away from the encoded items, which does not follow from the simple and transient attentional mechanisms assumed to generate the AAB. Selective allocation of attention is usually maintained over very short periods of time, hence, such a fleeting effect (i.e., AAB) would not have a strong effect on behavior and drinking decisions if no mnemonic component was additionally involved.

Despite these important differences, the interplay between attention and WM is essential for explaining the AMB and the relationship is well established within the literature (for review see Miyake & Shah, 1999). In its simplest conception attention is proposed to operate as a filter or a gateway to working memory, where information must be attended before it can be encoded (Cowan, 1999; Dehaene et al., 2003; O'Reilly, Braver, & Cohen, 1998) and/or successfully retrieved (Baars & Franklin, 2003; Kessler & Tipper, 2004; Oberauer, 2002). Cowan's (1999) suggestion that the allocation of attention is under the joint control of automatic (salient habituation) and voluntary (central executive) processes is of great relevance to the relationship between AAB and AMB, as it proposes that the automatic allocation of attention is particularly influenced by stimuli with a special significance to the participant, which are then encoded more efficiently into WM (Cowan, 1999; see also Wood & Cowan, 1995). Thus, chronic exposure to alcohol is likely to result in alcohol-related stimuli capturing attention in a relatively automatic manner, leading to more effective memory consolidation. Ceballos, Komogortsev, and Turner (2009) indeed reported that alcohol consumption predicted reflexive initial gaze fixations as well as the overall duration of fixations on alcohol-related photographs. This is in agreement with the notion of incentive-sensitization and with other approaches which explain addiction in terms of appetitive conditioning and learned associations that impact on the allocation of attention and cognitive control (for review, see Milton & Everitt, 2012; e.g., Robinson & Berridge, 2003; Stewart et al., 1984). Hence, biased attention is likely to result in more effective WM encoding.

Our previous research on selective attention (Kessler & Tipper, 2004; Tipper, Grison, & Kessler, 2003) has taken one step further by showing that selective attentional states do not only bias encoding but are also stored alongside a stimulus (e.g., face) into episodic memory and can influence processing (again) upon retrieval. This suggests that an AAB may influence WM processing also upon retrieval and not only during encoding. A tight relationship between efficiency of encoding and retrieval success is further corroborated by observations that rich contextual information such as "mood" can directly affect how well information is retrieved from memory (e.g., Bouton, 1993; Godden & Baddeley, 1980; LaBar & Cabeza, 2006; Smith & Vela, 2001). In particular, this has been demonstrated for stimuli associated with an emotion or presented in an emotional context (Erk et al., 2003; for review, see, e.g., LaBar & Cabeza, 2006; Lewis, Critchley, Smith, & Dolan, 2005; Palomba, Angrilli, & Mini, 1997; Teasdale & Fogarty, 1979). Hence, people who have frequent exposure and emotional/arousing associations with alcohol-related stimuli will generate richer representations of these items in WM, which might not only affect encoding but also the efficiency of retrieval. The other side of the same coin is that people who have only little exposure to alcohol-related stimuli might reveal better episodic memories for neutral items which they encounter more frequently. Our data support this conclusion.

In agreement with the notion of a tight interaction between attention and episodic memory, evidence from modeling, neuroimaging, and brain lesions has accumulated, suggesting a network of posterior parietal, prefrontal, and medial temporal brain areas as the neural substrate (Cashdollar et al., 2009; Kessler & Kiefer, 2005; O'Reilly et al., 1998; Rissman, Gazzaley, & D'Esposito, 2008; Sakai & Passingham, 2004; for review, see Zimmer, 2008). For the purpose of explaining drug-related AAB and AMB effects this framework would merely need to include mechanisms of conditioning and sensitization for explaining the emotional/motivational force of drug-related stimuli based on past experience (e.g., Robinson & Berridge, 2003; Stewart et al., 1984). Milton and Everitt (2012) have recently proposed such a comprehensive framework, where the effects of drug-related conditioning and sensitization in limbic, thalamic, and other midbrain areas are explained in the context of drug-related episodic memories linked to the medial temporal lobe as well as in relation to executive control, that is, selective attention, in the prefrontal cortex. The AMB effect reported here extends this model by specifying the interplay between stimuli, attention, and memory within this overarching framework. In particular, we suggest two possible mechanisms for how the AMB may impact on behavior. First, a WM bias for alcohol-related stimuli could directly influence choice behavior. For instance, if a person is biased toward remembering alcoholic drinks they have just seen in the kitchen/fridge, they will be more likely to choose one of these, when asked what they would like to drink. Second, working memory representations that are biased toward alcohol-related stimuli will contribute toward a corresponding bias in episodic long-term memory, thus further enhancing the ability of alcohol-related stimuli to capture attention and to be more effectively encoded into memory, thus contributing to a vicious circle.

In conclusion, we propose the following provisional model for explaining the AMB and its potential impact on drinking behavior. The AAB in more frequent drinkers is fuelled by past conditioning and sensitization to alcohol-related stimuli (Robinson & Berridge, 2003; Stewart et al., 1984). In turn the AAB enhances the representational strength of alcohol-related stimuli during encoding, leading to a subsequent alcohol memory bias (AMB) compared with infrequent drinkers (e.g., Jones et al., 2002; Jones et al., 2006). Because of richer and more emotional episodic associations in frequent drinkers, alcohol-related stimuli might also be less susceptible to interference during WM maintenance (cf. Kessler & Kiefer, 2005) and alcohol-related memory probes might be more effective retrieval cues than neutral probes (e.g., Cahill et al., 1996; Hamann, Ely, Grafton, & Kilts, 1999; LaBar & Cabeza, 2006; Palomba et al., 1997; Teasdale & Fogarty, 1979). Overall, better episodic WM performance for alcohol-related stimuli could then result in stronger long-term episodic memories (e.g., Baddeley, 2000), thus contributing to a vicious circle, where alcohol-related episodic memories in turn bias attention, WM, and behavior (e.g., Milton & Everitt, 2012). Our model offers a necessary extension to the transient nature of the AAB, by providing a more robust basis for explaining and predicting alcohol use. In the new model alcohol-related biases persist within the cognitive system over extensive timescales, thus providing numerous opportunities to influence present and future behavior and choices of alcohol users.

Conclusion

This is the first study to report an alcohol-related cognitive bias in WM processing that depended on the habits of alcohol use: heavier drinkers better remembered the correct location of alcohol-related images than infrequent drinkers, yielding a significant increase in memory bias with drinking score. This finding calls for further investigation of alcohol-related cognitive biases in WM, and we propose a theoretical model embedded within an overarching framework (Milton & Everitt, 2012) that may serve as a guide for future research by linking attention, working memory, and episodic long-term memory.

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