Response Inhibition Moderates the Relationship Between Implicit Associations and Drinking Behavior

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Background: Contemporary dual-process models of alcohol abuse propose that alcohol abuse develops because of dysfunctions in the impulsive system, which generates automatic impulses to drink alcohol, and disruptions in the reflective system, which becomes unable to inhibit the influence of these automatic impulses. Based on these insights, this study investigated whether individual differences in the ability of the reflective system to exert response inhibition moderate the relationship between automatic cognitive processes and drinking behavior. Specifically, it was examined whether the interaction between implicit alcohol-related associations and response inhibition predicted drinking behavior.

Methods: Seventy-one university students completed the study online via the Internet. Implicit alcohol associations with positive affect and with arousal were assessed with variants of the Implicit Association Test. Response inhibition was measured using the original Stroop task. Participants also reported their weekly alcohol use and alcohol-related problems.

Results: As predicted, implicit associations were unrelated to drinking behavior when response inhibition was high. In contrast, when response inhibition was low, stronger implicit associations between alcohol and positive affect predicted increased alcohol use and alcohol-related problems.

Conclusions: These findings indicate that the relationship between automatic cognitive processes, originating in the impulsive system, and drinking behavior depends on individual differences in response inhibition exerted by the reflective system. As prolonged alcohol abuse is known to impair response inhibition, alcohol abusers may benefit from interventions that increase response inhibition, thereby restoring inhibitory control over automatic impulses.

Key Words: Alcohol Use, Implicit Cognition, IAT, Stroop Interference, Response Inhibition.

ALCOHOL ABUSE AND dependence are characterized by a preoccupation with obtaining and drinking alcohol despite devastating physical, social, and occupational consequences. Dual-process theories propose that this aberrant behavior is determined by the dynamic interplay of 2 qualitatively different systems: a fast, associative, implicit, *impulsive* system, which includes automatic appraisal of stimuli in terms of their affective and motivational significance, and a slower, rule-based, explicit, *reflective* system, which includes controlled processes related to conscious deliberations, emotion regulation and expected outcomes (Deutsch and Strack, 2006; Evans, 2003; Evans and Coventry, 2006; Strack and Deutsch, 2004; Wiers and Stacy, 2006a,b; Wiers et al., 2007). While the reflective system determines behavior through conscious deliberation, the impulsive system activates behavioral schemata automatically through the process of spreading activation in an associative network (Strack and Deutsch, 2004). According to the dual-process theories, the impulsive system and the reflective system trigger simultaneous, conflicting signals, but ultimately, behavioral decisions are determined by the relative strengths of impulsive and reflective processes, so that stronger processes gain advantage over weaker ones (Bechara, 2005; Bechara et al., 2006; Deutsch and Strack, 2006; Strack and Deutsch, 2004). Dual-process models further state that behavior is to a large extent influenced by impulsive processes and that these impulsive processes can be regulated through controlled processing, but this requires motivation and cognitive resources that may not always be available (Fazio and Towles-Schwen, 1999; Wiers et al., 2007). For instance, a heavy drinker at a party may have the intention not to drink alcohol because he still has to drive home afterwards. However, as he is busy talking to some co-workers and friends, automatic impulsive responses activated by the sight of the pints of beer on the waiter's tray, may automatically trigger alcohol consumption despite his intention not to drink any alcohol.

Importantly, according to the dual-process models of addiction, the impulsive system becomes sensitized with repeated alcohol use, which increases the appetitive motivation to use alcohol (Wiers et al., 2007). In line with this idea, research using the Implicit Association Test (IAT;

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Received for publication August 25, 2008; accepted November 7, 2008.

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DOI: 10.1111/j.1530-0277.2008.00877.x

Greenwald et al., 1998) has demonstrated the existence of an implicit associative cluster involving the concept alcohol that presumably resides in the impulsive system and which is related to drinking behavior. The IAT is a computerized sorting task that infers implicit associations from the simultaneous classification of 2 target categories, for example alcohol versus soft drinks, and 2 affective attribute categories, for example positive versus negative. The target categories are combined with the attribute categories in 2 different sorting conditions (e.g., alcohol + positive versus soft drinks + negative and alcohol + negative versus soft drinks + positive) and the performance difference between these 2 sorting conditions reflects the strength of implicit associations between the target concepts and the attribute categories. Using the IAT, it was demonstrated that increased levels of alcohol use and abuse are related to stronger implicit associations between alcohol and positive affect, and to stronger implicit associations between alcohol and positive arousal (De Houwer et al., 2004; Houben and Wiers, 2006, 2007a,b; Wiers et al., 2002). Moreover, implicit alcohol associations with positive affect and arousal have been found to predict drinking behavior above the variance explained by explicit attitudes and alcohol-related expectancies (Houben and Wiers, 2006, 2007a,b; Wiers et al., 2002). Hence, these findings suggest that, in heavy drinkers and alcohol abusers, implicit alcohol associations with positive affect and with arousal are formed through experience. Consequently, these implicit associations are activated automatically whenever alcohol-related cues are encountered and stimulate alcohol use and abuse via the automatic activation of behavioral schemas (Strack and Deutsch, 2004).

Once the appetitive motivation to use alcohol has increased because of changes in the impulsive system, it becomes important whether one is able to control these impulses or gives in to them. This control over the impulsive system is achieved by the reflective system, but critically depends on one's ability and motivation to do so (Fazio and Towles-Schwen, 1999; Wiers et al., 2007). The ability of controlled processes to moderate the impact of spontaneous, impulsive processes is a central element of executive functioning, which can be defined as a set of cognitive control mechanisms that are relevant to goal-directed behavior. Among the executive functions, response inhibition, working memory updating, and mental set shifting have been identified as 3 essential abilities (Miyake et al., 2000). Thus, according to this dual-process view of addictive behaviors, individual differences in executive functioning determine whether automatic impulses to drink alcohol can be controlled or not. Consequently, individual differences in this ability may pose as a risk factor for developing an alcohol abuse problem. In addition, it has been suggested that prolonged alcohol use disrupts the operations of the reflective system, thereby compromising the cognitive capacity available for controlling automatic impulses (Wiers et al., 2007). Of the 3 core executive functions, primarily response inhibition and working memory updating appear to be affected by chronic alcohol abuse. Response inhibition can be defined as the capacity to inhibit prepotent responses and interference when engaged in goal-directed action (Miyake et al., 2000). Working memory updating refers to the ability to maintain and manipulate goal-relevant information in working memory (Conway et al., 2003; Miyake et al., 2000). Importantly, alcohol-dependent patients demonstrate deficits of both response inhibition (Noël et al., 2005, 2007a,b) and working memory, with primarily deficits in the ability to manipulate information held in memory, but not in the ability to store information in memory (Bechara and Martin, 2004; Noël et al., 2007a). Consequently, if executive functioning ability indeed moderates the impact of automatic impulses on drinking behavior, this could carry important implications for intervention strategies.

Present Research

In sum, dual-process models propose that alcohol abuse develops as the result of an imbalance between an impulsive system that becomes sensitized because of repeated alcohol use leading to increased appetitive motivation to use alcohol, and a regulatory reflective system that is compromised by prolonged exposure to alcohol. Moreover, there is also evidence for a neural division between these 2 systems: The impulsive system corresponds to subcortical structures including the amygdala, and basal ganglia, while the reflective system corresponds to frontal cortical structures such as the lateral prefrontal cortex (e.g., Satpute and Lieberman, 2006). Further, it should be noted that this model is also consistent with neurobiological models and neuroimaging of addictive behaviors that also state the importance of both sensitized reward processes (related to subcortical dysfunction) and disrupted inhibitory control (related to frontal cortical dysfunction) as a result of long-term substance abuse (e.g., Goldstein and Volkow, 2002; Lubman et al., 2004; Robinson and Berridge, 2003).

Importantly, this dual-process model specifically predicts that individual differences in executive functioning moderate the influence of automatic impulsive processes on drinking behavior. In line with this prediction, it was recently demonstrated that working memory moderates the relationship between implicit alcohol associations and drinking behavior (Thush et al., 2008). Specifically, implicit alcohol associations with positive arousal predicted alcohol use for participants who scored low on a working memory task, but not for participants with high scores on the working memory task. The goal of the present research was to examine the same prediction with respect to response inhibition, which, like working memory, is also a critical component of executive functioning that becomes impaired after long-term alcohol abuse (Bechara and Martin, 2004; Noël et al., 2005, 2007a,b). Specifically, we examined whether individual differences in response inhibition moderate the influence of implicit alcohol associations on drinking behavior.

It should be noted that inhibition-related processes appear to be a family of functions rather than a single unitary construct, including prepotent response inhibition, resistance to distractor interference, and resistance to proactive interference (Friedman and Miyake, 2004). We were mainly interested in the ability to inhibit prepotent responses and we measured this ability with the Stroop task (Stroop, 1935). Although the Stroop task is sometimes classified as a resistance to interference task (e.g., Nigg, 2000), it differs in that the response that must be avoided is dominant for literate individuals (Macleod, 1991). Moreover, the Stroop task has been demonstrated to tap prepotent response inhibition (Friedman and Miyake, 2004). Further, we used a bipolar IAT to assess implicit alcohol associations with positive versus negative affect (Houben and Wiers, 2007b; Wiers et al., 2002) and a unipolar IAT to measure implicit alcohol associations with arousal (Houben and Wiers, 2006). We predicted that implicit alcohol associations would predict drinking behavior more strongly for participants who demonstrated low response inhibition compared to participants with a high ability to inhibit automatic responses.

MATERIALS AND METHODS

Participants

We recruited 71 participants (63 females; mean age = 20.49 years, SD = 2.03) through advertisements in the buildings of Maastricht University. Participants on average consumed 8.20 (SD = 9.81; range 0 to 59) Dutch standard drinking units of 10 g of alcohol, measured with a self-report questionnaire (Wiers et al., 1997) based on the timeline follow-back method (TLFB; Sobell and Sobell, 1990). On the Alcohol Use Disorder Identification Test (AUDIT; Saunders et al., 1993), participants scored 7.21 on average (SD = 3.60; range 2 to 17); 34% scored above 8, indicating hazardous drinking (Palfai and Ostafin, 2003), and 21% scored above 10 which is the cut-off score for alcohol problems (Saunders et al., 1993).

Materials and Measures

Implicit Association Test. Both the bipolar IAT and the unipolar IAT presented 2 target categories: an alcohol target category (wine, beer, pint, vodka, breezer, and whisky; label "alcohol") and a soft drink target category (coca-cola, fanta, orange soda, cassis, juice, and water; label "soda"). The (Dutch) target categories were matched on number of syllables. Further, in the bipolar IAT, a positive attribute category (love, sunshine, warmth, peace, hug, and rainbow; label "pleasant") was paired with a negative attribute category (sorrow, war, depression, pain, fight, and disease; label "unpleasant"). The (Dutch) positive and negative attribute categories were matched on number of syllables. Finally, in the unipolar IAT, an arousal attribute category (talkative, excited, cheerful, happy, funny, and energetic; label "active") was contrasted with a neutral attribute category (average, indefinite, general, normal, habitual, and ordinary; label "neutral"). The (Dutch) arousal category and neutral category were matched on number of syllables.

Both the bipolar IAT and the unipolar IAT followed the standard IAT procedure (Greenwald et al., 1998; see Table 1). In the first block, participants practiced the classification of the target stimuli as "alcohol" or "soft drink" using a left and a right response key during 24 trials. In the second block, participants practiced the classification of the attribute stimuli (i.e., "pleasant" vs. "unpleasant" or "active" vs. "neutral") using the same response keys during 24 trials. In the third block, participants practised the combined classification of the target and attribute categories. During 24 trials, participants had to classify stimuli belonging to one target category and one attribute category (e.g., alcohol and pleasant) with one response key and stimuli belonging to the other target category or the other attribute category (e.g., soft drinks and unpleasant) with the other response key. The fourth block was the first test block, which consisted of 48 trials with the same instruction as the third block. During the fifth block, the participants practiced the reversed response assignment of the target categories during 48 trials. In the sixth block, participants practised the reversed combination of targets and attributes during 24 trials (e.g., alcohol and negative vs. soft drinks and positive). Finally, the seventh block was the reversed combination test block, which had the same instruction as the sixth block and which consisted of 48 trials.

Table 1. Overview of the IAT Procedure

IAT				
Block	Trials	Function	Left key	Right key
1	24	Target practice	Alcohol	Soft drinks
2	24	Attribute practice	Pleasant	Unpleasant
3	24	Combination practice	Alcohol Pleasant	Soft drinks Unpleasant
4	48	Combination test	Alcohol Pleasant	Soft drinks Unpleasant
5	48	Reversed target practice	Soft drinks	Alcohol
6	24	Reversed combination practice	Soft drinks Pleasant	Alcohol Unpleasant
7	24	Reversed combination test	Soft drinks Pleasant	Alcohol Unpleasant

IAT, Implicit Association Test.

Blocks are shown for the bipolar IAT. In the unipolar IAT, the procedure was the same, only the attribute categories were replaced with "active" versus "neutral." The assignment of the target and attribute categories to the left and right response key was counterbalanced across participants.

The response assignment of the target categories and the attribute categories was counterbalanced across participants. Stimuli were always presented in the middle of the computer screen and the labels of the categories assigned to the left and right response key were presented in the corresponding upper corners of the computer screen. Stimuli remained on screen until a correct response was given. The inter trial interval was 250 ms. Feedback was presented in red beneath the stimuli after an incorrect response ("wrong").

Stroop Task. During the original color Stroop task, the participants' task was to determine the color (i.e., yellow, green, blue, or red) of words and symbols that appeared on the computer screen by pressing 1 of 4 keys on the keyboard. During the first block, participants practiced the response assignment of the colors. This practice block consisted of 48 trails during which 4 symbols (i.e., &&&&, = = = =, %%%%, and ####) were presented in the colors yellow, blue, red, and green. Stimuli remained on screen until they pressed the correct response key. During the second block, which was the test block, participants indicated the colors in which the words "blue," "green," "yellow," and "red" were presented using the same response keys. The test block also consisted of 48 trials, including 24 congruent trials and 24 incongruent trials. During the congruent trials, the meaning of the words and the color in which they were presented were compatible (e.g., "red" presented in the color red). During the incongruent trials, the meaning of the words was incompatible with the color in which they were presented (e.g., "red" presented in the color green). During both the practice and the test block, stimuli were presented in random order with the restriction that words and symbols were never presented in the same color during 2 consecutive trials.

Procedure

All participants were tested via the Internet. Advertisements invited people to visit the website http://www.impliciet.eu where they received further information about the experiment and a consent form. After giving consent, participants performed a bipolar IAT and a unipolar IAT (in balanced order). This Internet-based assessment of implicit alcohol-related associations was recently also validated by Houben and Wiers (2008). Next, participants performed the original Stroop task. The online IAT versions and the online Stroop task were all programmed in Macromedia Flash Professional (2005). Finally, participants filled out the TLFB and the AUDIT, in this order. The online TLFB and AUDIT were developed using Microsoft Frontpage (2002). When all participants were tested, participants were provided with debriefing information about the purpose of the study and they received a gift certificate of €15 for participating.

RESULTS

Preliminary Analyses

Implicit Association Test effects were calculated according to the D600 scoring algorithm suggested by Greenwald and colleagues (2003). For both the bipolar IAT and the unipolar IAT, the D600 measure was calculated so that higher scores indicate faster performance for the compatible response assignment (i.e., "alcohol" + "pleasant"/"active" vs. "soda" + "unpleasant"/"neutral") than for the incompatible response assignment (i.e., "alcohol" + "unpleasant"/ "neutral" vs. "soda" + "pleasant"/"active"). Analyses revealed no influential outliers on IAT data. The bipolar IAT yielded a significant IAT effect, $t(70) = -11.96$, $p < 0.001$, indicating that participants were faster when alcohol was paired with the negative category than when alcohol was paired with the positive category. The unipolar IAT also showed a significant IAT effect, $t(70) = 5.15$, $p < 0.001$, which demonstrates that participants were faster when alcohol was paired with the arousal category than when alcohol was paired with the neutral category.

For the Stroop task, we calculated mean log-transformed response latencies separately for the congruent test trials and for the incongruent test trials. Results showed a significant Stroop effect, $t(70) = -12.13$, $p < 0.001$, indicating that color-naming was faster during congruent trials than during incongruent trials. Next, a measure of response inhibition was calculated by subtracting the average log-transformed response latencies during the congruent trials from the average log-transformed response latencies during the incompatible trials. Thus, higher scores on this measure indicate greater Stroop interference. No influential outliers were found on Stroop interference scores.

Alcohol consumption during the past week was estimated from the TLFB. Alcohol-related problems were estimated from the average AUDIT score. We applied a natural log-transformation to both estimated alcohol consumption and the AUDIT score to achieve a normal distribution for both variables. Correlations between IAT effects, Stroop interference scores, alcohol use, and alcohol-related problems are shown in Table 2.

Table 2. Correlations of Bipolar and Unipolar IAT Versions, Stroop Interference Scores, Alcohol Consumption, and Alcohol-Related Problems

	Bipolar IAT	Unipolar IAT	Stroop interference	Alcohol consumption	Alcohol problems
Bipolar IAT	–				
Unipolar IAT	0.15	–			
Stroop interference	−0.01	−0.28*	–		
Alcohol consumption	0.15	0.22#	−0.15	–	
Alcohol problems	0.22#	0.31**	−0.29*	0.71**	–

$N = 71$, #$p \leq 0.10$ (two-tailed), *$p < 0.05$ (two-tailed), **$p < 0.01$ (two-tailed).

Alcohol Use and Alcohol-Related Problems

An index of alcohol use and alcohol-related problems (AUP) was calculated as the mean of alcohol consumption and AUDIT scores.[1] Hence, higher scores on the AUP index indicate higher levels of alcohol consumption and increased alcohol-related problems. To test the prediction that response inhibition moderates the relationship between implicit alcohol associations and alcohol use and alcohol-related problems, we performed multiple regression analyses on the AUP index.[2] As predictors, we entered IAT effects, Stroop interference scores and the interaction between IAT effects and Stroop interference. Separate multiple regression analyses were performed for the bipolar IAT and the unipolar IAT. Following Cohen and colleagues (2003), all predictor variables were centered and interaction terms were computed from these centered scores.

The multiple regression analyses on the prediction of AUP by the bipolar IAT, the Stroop task, and their interaction term, $R^2 = 0.15$, $F(3,67) = 3.99$, $p = 0.011$, confirmed the expected interaction between implicit affective associations and response inhibition. Scores on the bipolar IAT significantly predicted AUP, $\beta = 0.26$, $t(67) = 2.25$, $p = 0.027$, while the prediction by the Stroop task was only borderline significant, $\beta = -0.20$, $t(67) = -1.73$, $p = 0.089$. Importantly, the interaction between scores on the bipolar IAT and Stroop performance was also significant, $\beta = 0.25$, $t(67) = 2.13$, $p = 0.037$. This interaction was further examined by plotting the simple slopes of AUP on IAT scores at low (1 SD below the mean) and high (1 SD above the mean) levels of Stroop interference, and testing whether these simple slopes differed significantly from zero (Cohen et al., 2003). Figure 1 illustrates the simple slopes of AUP as a function of weak (1 SD below the mean) versus strong (1 SD above the

[1]Because alcohol consumption and alcohol-related problems were measured with different scales, both variables were *z*-transformed before calculating the AUP index.

[2]Results were highly similar when log-transformed alcohol use and log-transformed alcohol-related problems were entered as dependent variables in separate multiple regression analyses.

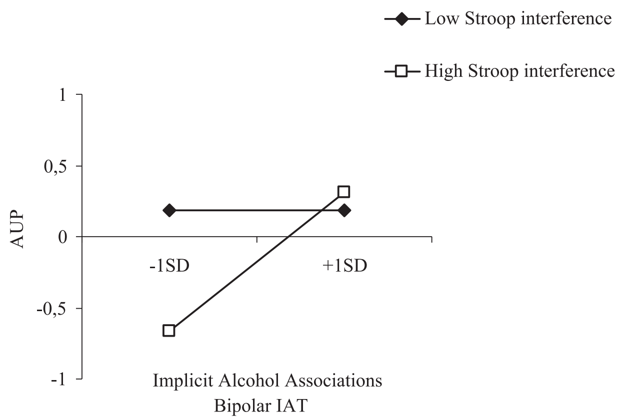

Fig. 1. Alcohol use and alcohol-related problems (AUP) as a function of weak versus strong implicit alcohol associations with positive affect measured with the bipolar Implicit Association Test (IAT) (respectively 1 SD below and 1 SD above the mean IAT score) and low versus high Stroop interference (respectively 1 SD below and 1 SD above the mean Stroop score).

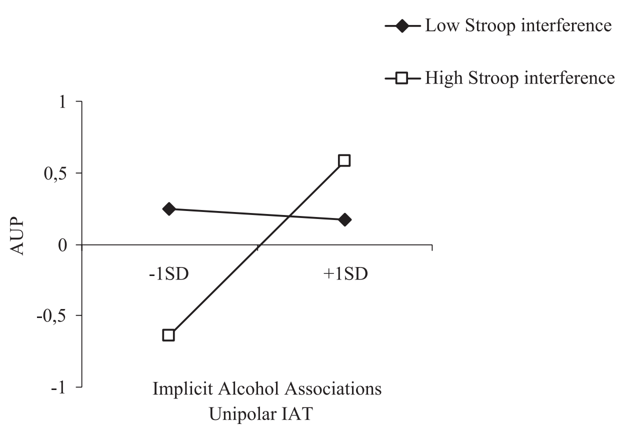

Fig. 2. Alcohol use and alcohol-related problems (AUP) as a function of weak versus strong implicit alcohol associations with arousal measured with the unipolar Implicit Association Test (IAT) (respectively 1 SD below and 1 SD above the mean IAT score) and low versus high Stroop interference (respectively 1 SD below and 1 SD above the mean Stroop score).

mean) implicit alcohol associations with positive affect at low versus high Stroop interference. As can be seen in Fig. 1, AUP increased significantly as a function of the strength of positive implicit alcohol associations for participants who demonstrated high interference on the Stroop task, $\beta = 0.53$, $t(67) = 2.76$, $p = 0.007$, as confirmed by a simple slope test. In contrast, for participants who demonstrated low interference on the Stroop task, the strength of positive implicit alcohol associations was unrelated to AUP, $\beta = 0.01$, $t(67) = 0.01$, $p = 0.997$.

Similarly, the multiple regression analyses on the prediction of AUP by the unipolar IAT, the Stroop task, and their interaction term, $R^2 = 0.19$, $F(3,67) = 5.32$, $p = 0.002$, showed that scores on the unipolar IAT significantly predicted AUP, $\beta = 0.31$, $t(67) = 2.64$, $p = 0.010$, while Stroop interference was not a significant predictor of AUP, $\beta = -0.13$, $t(67) = -1.13$, $p = 0.264$. In addition, the interaction between scores on the unipolar IAT and Stroop performance was significant, $\beta = 0.30$, $t(67) = 2.65$, $p = 0.010$. This interaction is illustrated in Fig. 2 by plotting the simple slopes of AUP as a function of weak (1 SD below the mean) versus strong (1 SD above the mean) implicit alcohol associations with arousal at low (1 SD below the mean) versus high (1 SD above the mean) Stroop interference. Figure 2 shows that AUP increased significantly as a function of the strength of implicit alcohol associations with arousal for participants who demonstrated high interference on the Stroop task, $\beta = 0.66$, $t(67) = 3.38$, $p = 0.001$, but not for participants who demonstrated low interference on the Stroop task, $\beta = -0.04$, $t(67) = -0.25$, $p = 0.805$.

DISCUSSION

The goal of this study was to test the prediction that individual differences in response inhibition moderate the relationship between implicit alcohol associations and drinking behavior in a sample of nondependent problem drinkers. Using the Stroop task as a measure of response inhibition, results demonstrated that positive implicit alcohol associations and implicit associations between alcohol and arousal predicted drinking behavior only for participants with high Stroop interference scores. In contrast, for participants with low Stroop interference scores, the strength of implicit alcohol associations was unrelated to drinking behavior. Hence, these results demonstrate that the ability to inhibit automatic responses determines whether or not drinking behavior is predicted by implicit alcohol associations. The present findings are similar to previous findings showing that working memory capacity moderates the prediction of drinking behavior by implicit alcohol associations (Thush et al., 2008). Together, these results indicate that the relationship between implicit alcohol associations and drinking behavior is influenced by working memory and response inhibition, which have both been identified as essential executive functioning abilities. When working memory is somehow limited or participants experience difficulty inhibiting automatic responses, drinking behavior is predicted by implicit alcohol associations that reside in the impulsive system. Conversely, drinking behavior is unrelated to drinking behavior in participants with high working memory capacity or high response inhibition ability. Instead, their drinking behavior appears to be more strongly related to explicit alcohol-related cognitions which reside in the reflective system (Thush et al., 2008).

Together, these findings are consistent with contemporary dual-process account of addictive behavior. These models propose that problematic drinking develops and is maintained as the result of dysfunctions in 2 systems. On the one hand, the impulsive system undergoes changes in its associative network which generates automatic impulses to drink alcohol. On the other hand, the reflective system becomes impaired and is no longer able to inhibit the automatic impulses triggered by the impulsive system (Bechara et al., 2006; Deutsch and Strack, 2006; Evans and Coventry, 2006; Strack and Deutsch, 2004; Wiers and Stacy, 2006a,b; Wiers et al., 2007).

Hence, according to this dual-process view, problem-drinking is characterized by an imbalance between the impulsive system and the reflective system, which causes drinking behavior to be more strongly determined by the impulsive system. Specifically, this dual-process model predicts that individual differences in executive functioning act as a moderator for the influence of the impulsive system on drinking behavior. This prediction was confirmed by the present findings as well as the findings by Thush and colleagues (2008).

Hence, these findings indicate that individual differences in executive functioning, and specifically in working memory and response inhibition, may pose as risk factors in problematic drinking behavior as well as for the development of alcohol abuse and dependence. Besides individual differences in executive functioning, there are also other individual risk factors for developing alcohol dependence that can be related to all aspects of the model, including individual differences in the sensitivity to reward, and to rewarding effects of alcohol in particular (see Wiers et al., 2007). Further, it has to be noted that impaired executive functioning has already been identified as a possible risk factor for alcohol abuse (Finn and Hall, 2004). However, the present results further extend these findings by offering new insights on why this might be the case: Limited executive functioning ability diminishes the capacity for executive control over the impulsive system. As a result, behavior may be guided more strongly by impulsive cognitive processes, which are automatically activated by alcohol-related cues and which automatically activate behavioral schemas that compel alcohol consumption. In line with this conclusion, Finn and Hall (2004) have proposed 2 mechanisms for the moderating influence of executive functioning, and more specifically of working memory capacity, on the relationship between personality risk and drinking behavior. First, low working memory capacity may make it difficult to shift attention away from highly salient stimuli and toward less salient stimuli. Second, immediate contingencies are more salient while delayed contingencies are less salient for impulsive people. The moderating influence of executive functioning then suggests that people who are less able to actively manage less salient but adaptive goals when faced with salient, distracting information are more likely to let their behavior be guided by this distracting information. The present findings suggest that this distracting information includes implicit associations with alcohol that are automatically activated in the impulsive system.

Further, the finding that individual differences in both working memory and response inhibition moderate the relationship between automatic impulsive processes and drinking behavior may carry important clinical implications. Specifically, research has demonstrated that chronic alcohol abuse causes impairments in both working memory and response inhibition in alcohol-dependent patients (Bechara and Martin, 2004; Noël et al., 2005, 2007a,b). Consequently, dual-process theories as well as the current findings suggest that this may result in a loss of control over responses that are automatically triggered in the impulsive system. Ultimately, this could cause their drinking behavior to be determined to an increasing extent by automatic impulsive processes, which further compel alcohol use, leading to a vicious circle of further deterioration of executive functioning abilities. However, whether the present findings also generalize to alcohol-dependent patients remains an issue for future research. If the present findings indeed generalize to clinical settings, intervention programs could benefit from training strategies that strengthen executive functioning abilities, including response inhibition and working memory. Indeed, research has shown that executive functions and their underlying brain regions are plastic and adaptive, and that they can be modified through training procedures (Erickson et al., 2007; Klingberg et al., 2005; Olesen et al., 2004). Typically, these training procedures include extensive practice with 1 or more executive functioning tasks during which the difficulty of the task systematically increases. However, up to this point, it has not yet been examined whether alcohol abusers might profit from such executive functioning training. Future research has to indicate whether training of executive control functions are effective in restoring executive control over impulsive processes in different clinical and nonclinical populations. Nevertheless, even if the level of executive functioning can be increased through training procedures, one still needs to be motivated or have a goal in mind to apply this executive control. As some dual-process theories have pointed out, the influence of impulsive processes on behavior depends on not only the ability to control impulsive processes, but also on the motivation to do so (Fazio and Towles-Schwen, 1999). Thus, future research also has to examine whether motivational interventions have a moderating effect on the influence of impulsive processes on drinking behavior and how this relates to the value of executive functioning training.

Another approach for intervention strategies could be to focus on directly changing implicit alcohol associations. Interestingly, Gawronski and Bodenhausen (2006) recently proposed the Associative-Propositional Evaluation model that specifies under which conditions changes are expected in implicit cognitions, explicit cognitions or both. Specifically, they advocate that a direct change in implicit cognitive processes can be expected when the associative structure is changed, for example, by introducing new associations through evaluative conditioning, or when the temporal activation of pre-existing associations is changed, for example, due to context cues. A direct approach to changing implicit cognitive processes, thus, is the construction of new implicit associations through evaluative conditioning. An example of this approach can be found in a series of studies by Olson and Fazio (2006), demonstrating that an evaluative conditioning procedure reduced prejudice against black people as indicated by an evaluative priming measure of implicit racial attitudes. Given these promising results, it should be interesting to explore whether an evaluative conditioning procedure could also succeed in changing implicit alcohol-related associations and whether such an approach will also produce corresponding changes in drinking behavior.

There are some limitations in this study that call for future research. First, as mentioned above, the generalizability of the present findings to alcohol dependent patients needs to be further examined. For instance, it would be interesting to test whether impulsive processes show a stronger relationship with drinking behavior in a sample of alcohol-dependent patients compared to a sample of nondependent heavy drinkers. If the present findings can be extended to clinical populations, it would further be interesting to examine whether executive functioning can be increased through training and whether this translates into a decrease in drinking behavior. Second, our choice of the Stroop task as a measure of prepotent response inhibition was based on previous research by Friedman and Miykae (2004). However, the role of inhibition in Stroop interference is highly debated (see review by Macleod, 1991) and, therefore, it would be interesting to see if the present findings could be replicated using a different measure of prepotent response inhibition such as the stop-signal task (Logan, 1994) or the antisaccade task (Hallett, 1978). Third, we did not measure substance use besides alcohol use in the present sample, nor did we measure psychopathology. However, it should be noted that both are typically relatively low in student samples. Nevertheless, it could be interesting for future research to examine the impact of psychopathology on implicit measures and on inhibitory control. In addition, it would be interesting to examine whether the present findings can be replicated with other addictive substances. Finally, it should be noted that the present results, as well as the results of Thush and colleagues (2008), are correlational in nature, so future research needs to determine the causality of the relationship between implicit alcohol associations and drinking behavior as well as the moderating role of executive functioning.

In conclusion, the present findings supported our hypothesis that response inhibition moderates the relationship between implicit alcohol associations and drinking behavior. These findings are consistent with contemporary dual-process models, which attribute the development of alcohol abuse to both hyperactive responsiveness of an impulsive system and dysfunctions in a reflective system that is no longer able to inhibit automatic responses generated in the impulsive system. These new insights also suggest possible ways forward regarding the treatment of alcohol abuse and dependence. Future research needs to examine whether current interventions might benefit from new training procedures designed to enhance executive functioning and thereby restore executive control over drinking behavior.

ACKNOWLEDGMENT

This research was supported by a grant from the Technology Foundation STW.

REFERENCES

Bechara A (2005) Decision making, impulse control and loss of willpower to resist drugs: a neurocognitive perspective. Nat Neurosci 8:1458–1463.

Bechara A, Martin EM (2004) Impaired decision making related to working memory deficits in individuals with substance addictions. Neuropsychology 18:152–162.

Bechara A, Noel X, Crone EA (2006) Loss of willpower: abnormal neural mechanisms of impulse control and decision making in addiction, in *Handbook of Implicit Cognition and Addiction* (Wiers RW, Stacy AW eds), pp 215–232. SAGE Publishers, Thousand Oaks, CA.

Cohen J, Cohen P, West SG, Aiken LS (2003) Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences. Lawrence Erlbaum Associates, Mahwah, NJ.

Conway ARA, Kane MJ, Engle RW (2003) Working memory capacity and its relation to general intelligence. Trends Cogn Sci 7:547–552.

De Houwer J, Crombez G, Koster EHW, De Beul N (2004) Implicit alcohol-related cognitions in a clinical sample of heavy drinkers. J Behav Ther Exp Psychiatry 35:275–286.

Deutsch R, Strack F (2006) Reflective and impulsive determinants of addictive behavior, in *Handbook of Implicit Cognition and Addiction* (Wiers RW, Stacy AW eds), pp 45–57. SAGE Publishers, Thousand Oaks, CA.

Erickson KI, Colcombe SJ, Wadhwa R, Bherer L, Peterson MS, Scalf PE, Kim JS, Alvarado M, Kramer AF (2007) Training-induced functional activation changes in dual-task processing: an fMRI study. Cereb Cortex 17:192–204.

Evans JSBT (2003) In two minds: dual-process accounts of reasoning. Trends Cogn Sci 7:454–459.

Evans JSBT, Coventry K (2006) A dual process approach to behavioural addiction: the case of gambling, in *Handbook of Implicit Cognition and Addiction* (Wiers RW, Stacy AW eds), pp 29–43. SAGE Publishers, Thousand Oaks, CA.

Fazio RH, Towles-Schwen T (1999) The MODE model of attitude-behavior processes, in *Dual-Process Theories in Social Psychology* (Chaiken S, Trope Y eds), pp 97–116. The Guilford Press, NY/London.

Finn PR, Hall E (2004) Cognitive ability and risk for alcoholism: short-term memory capacity and intelligence moderate personality risk for alcohol problems. J Abnorm Psychol 113:569–581.

Friedman NP, Miyake A (2004) The relations among inhibition and interference control functions: a latent-variable analysis. J Exp Psych Gen 133:101–135.

Goldstein RZ, Volkow ND (2002) Drug addiction and its underlying neurobiological basis: neuroimaging evidence for the involvement of the frontal cortex. Am J Psychiatry 159:1642–1652.

Gawronski B, Bodenhausen GV (2006) Associative and propositional processes in evaluation: an integrative review of implicit and explicit attitude change. Psych Bull 132:692–731.

Greenwald AG, McGhee DE, Schwartz JLK (1998) Measuring individual differences in implicit cognition: the Implicit Association Test. J Pers Soc Psychol 74:1464–1480.

Greenwald AG, Nosek BA, Banaji MR (2003) Understanding and using the implicit association test: I. An improved scoring algorithm. J Pers Soc Psychol 85:197–216.

Hallett PE (1978) Primary and secondary saccades to goals defined by instructions. Vision Res 18:1279–1296.

Houben K, Wiers RW (2006) Assessing implicit alcohol associations with the Implicit Association Test: fact or artifact? Addict Behav 31:1346–1362.

Houben K, Wiers RW (2007a) Are drinkers implicitly positive about drinking alcohol? Personalizing the alcohol-IAT to reduce negative extrapersonal contamination. Alcohol 42:301–307.

Houben K, Wiers RW (2007b) Personalizing the alcohol-IAT with individualized stimuli: relationship with drinking behavior and drinking-related problems. Addict Behav 32:2852–2864.

Houben K, Wiers RW (2008) Measuring implicit alcohol associations via the Internet: validation of web-based Implicit Association Tests. Behav Res Methods 40:1134–1143.

Klingberg T, Fernell E, Olesen PJ, Johnson M, Gustafsson P, Dahlström K, Gillberg CG, Forssberg H, Westerberg H (2005) Computerized training of working memory in children with ADHD. A randomized, controlled trial. J Am Acad Child Adolesc Psychiatry 44:177–186.

Logan GD (1994) On the ability to inhibit thought and action: a user's guide to the stop signal paradigm, in *Inhibitory Processes in Attention, Memory, and Language* (Dagenbach RW, Carr TH eds), pp 189–239. Academic Press, San Diego, CA.

Lubman DI, Yücel M, Pantelis C (2004) Addiction, a condition of compulsive behaviour? Neuroimaging and neuropsychological evidence of inhibitory dysregulation. Addiction 99:1491–1502.

Macleod CM (1991) Half a century of research on the Stroop effect: an integrative review. Psychol Bull 109:163–203.

Macromedia Flash Professional [computer program]. Version 8.0. San Jose, CA: Adobe Systems Inc; 2005.

Microsoft Frontpage [computer program]. Redmond, WA: Microsoft Corporation; 2002.

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A (2000) The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. Cognit Psychol 41:49–100.

Nigg JT (2000) On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working memory taxonomy. Psychol Bull 126:220–246.

Noël X, Bechara A, Dan B, Hanak C, Verbanck P (2007a) Response inhibition deficit is involved in poor decision making under risk in nonamnesic individuals with alcoholism. Neuropsychology 21:778–786.

Noël X, Van der Linden M, d'Acremont M, Bechara A, Dan B, Hanak C, Verbanck P (2007b) Alcohol cues increase cognitive impulsivity in individuals with alcoholism. Psychopharmacology (Berl) 192:291–298.

Noël X, Van der Linden M, d'Acremont M, Colmant M, Hanak C, Pelc I, Verbanck P, Bechara A (2005) Cognitive biases toward alcohol-related words and executive deficits in polysubstance abusers with alcoholism. Addiction 100:1302–1309.

Olesen PJ, Westerberg H, Klingberg T (2004) Increased prefrontal and parietal activity after training of working memory. Nat Neurosci 7:75–79.

Olson MA, Fazio RH (2006) Reducing automatically-activated racial prejudice through implicit evaluative conditioning. Personality Social Psych Bull 32:421–433.

Palfai TP, Ostafin BD (2003) Alcohol-related motivational tendencies in hazardous drinkers: assessing implicit response tendencies using the modified-IAT. Behav Res Ther 41:1149–1162.

Robinson TE, Berridge KC (2003) Addiction. Annu Rev Psychol 54:25–53.

Satpute AB, Lieberman MD (2006) Integrating automatic and controlled processes into neurocognitive models of social cognition. Brain Res 1079:86–97.

Saunders JB, Aasland OG, Babor TF, De la Fuente JR, Grant M (1993) Development of the Alcohol use Disorders Identification Test (AUDIT): WHO collaborative project on early detection of persons with harmful alcohol consumption. Addiction 88:791–804.

Sobell LC, Sobell MB (1990) Self-report issues in alcohol abuse: state of the art and future directions. Behav Assess 12:77–90.

Strack F, Deutsch R (2004) Reflective and impulsive determinants of social behavior. Pers Soc Psychol Rev 8:220–247.

Stroop JR (1935) Studies of interference in serial verbal reactions. J Exp Psychol 18:643–661.

Thush C, Wiers RW, Ames SL, Grenard JL, Sussman S, Stacy AW (2008) Interactions between implicit and explicit cognition and working memory capacity in the prediction of alcohol use in at-risk adolescents. Drug Alcohol Depend 94:116–124.

Wiers RW, Bartholow BD, van den Wildenberg E, Thush C, Engels RCME, Sher KJ, Grenard JL, Ames SL, Stacy AW (2007) Automatic and controlled processes and the development of addictive behaviors in adolescents: a review and a model. Pharmacol Biochem Behav 86:263–283.

Wiers RW, Hoogeveen K-J, Sergeant JA, Gunning WB (1997) High- and low-dose alcohol-related expectancies and the differential associations with drinking in male and female adolescents and young adults. Addiction 92:871–888.

Wiers RW, Stacy AW eds (2006a) Handbook of Implicit Cognition and Addiction. SAGE Publications, Thousand Oaks, CA.

Wiers RW, Stacy AW (2006b) Implicit cognition and addiction. Curr Dir Psychol Sci 15:292–296.

Wiers RW, van Woerden N, Smulders FTY, de Jong PJ (2002) Implicit and explicit alcohol-related cognitions in heavy and light drinkers. J Abnorm Psychol 111:648–658.