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Executive Functions and Motivation as Moderators of the Relationship Between Automatic Associations and Alcohol Use in Problem Drinkers Seeking Online Help

Denise S. van Deursen, Elske Salemink, Wouter J. Boendermaker, Thomas Pronk, Wilhelm Hofmann, and Reinout W. Wiers

Background: Dual process models posit that problem drinking is maintained by an imbalance between relatively strong automatic processes and weak controlled processes, a combination of executive functions and motivation. Few studies have examined how the interplay between automatic processes and executive functions is affected by motivation to change. This study examined this relationship in problem drinkers seeking online help to change their alcohol use. It was expected that executive functions (i.e., working memory, response inhibition) would moderate the relationship between automatic (valence and approach) associations and alcohol use and that this effect would be stronger in individuals with strong motivation to change.

Methods: A sample of 302 problem drinkers (mean age: 51.7 years) participated in this study as part of the baseline assessment before an Internet intervention. Participants completed an online version of the brief Implicit Association Test (valence and approach associations), the self-ordered pointing task (working memory), the Stroop task (response inhibition), the Readiness to Change Questionnaire (motivation to change), and the Timeline Follow-Back Questionnaire (alcohol use). Hierarchical moderated regression analysis was used to test the 4 hypothesized 3-way interactions.

Results: As expected, the interaction between valence associations and working memory only predicted alcohol use among individuals with strong motivation. This pattern was neither found for response inhibition nor for approach associations.

Conclusions: Results provide partial support for the moderating role of motivation in the interplay between automatic processes and executive functions. Future studies should investigate this relationship in participants with the full range of motivation and alcohol use.

Key Words: Problem Drinking, Automatic Associations, Executive Functions, Motivation to Change, Brief Implicit Association Test.

ONE OF THE defining characteristics of alcohol dependence is the continuation of excessive alcohol use, despite the motivation to restrain or reduce (American Psychiatric Association, 2013). Dual process models of addiction (Gladwin et al., 2011; Wiers et al., 2007) attribute this discrepancy between motivation and behavior to an imbalance between automatic and controlled cognitive determinants of alcohol use. Automatic processes are relatively fast, require lower levels of cognitive resources, and are less amendable to conscious effort. Extended periods of heavy drinking are thought to increase the strength of automatic processes, resulting in a selective attention for alcohol-related cues, automatic positive and approach associations with alcohol, and automatic action tendencies toward alcohol. The extent to which these automatic biases influence alcohol use is thought to depend on controlled processes: a combination of the motivation to restrain and executive functions. Several executive functions can been distinguished, including set shifting, updating and monitoring working memory, and inhibiting a prepotent response (Miyake et al., 2000). Although separable, these functions also show considerable overlap, which is likely caused by shared task demands and the fact that they all require suppression of irrelevant information (Miyake et al., 2000). In the context of dual process models, working memory and response inhibition have been studied most.

Several studies in (at-risk) adolescents and heavy-drinking students have found evidence that the influence of automatic processes on alcohol use is moderated by working memory or response inhibition. In line with the predictions derived from dual process theories, automatic biases were shown to be more strongly related to alcohol use in individuals with

From the Addiction Development and Psychopathology (ADAPT) Lab (DSD, ES, WJB, TP, RWW), Department of Psychology, University of Amsterdam, Amsterdam, the Netherlands; and Social Cognition Center Cologne (WH), University of Cologne, Cologne, Germany.

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Reprint requests: Denise van Deursen, MSc, Addiction Development and Psychopathology (ADAPT) Lab, Department of Psychology, University of Amsterdam, Weesperplein 4, 1018 XA Amsterdam, the Netherlands. Tel.: +31-(0)20-5256212; Fax: +31-(0)20-639-0279; E-mail: d.s.vandeursen@uva.nl

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low compared to high working memory (Grenard et al., 2008; Salemink and Wiers, 2014; Thush et al., 2008) and response inhibition (Houben and Wiers, 2009; Peeters et al., 2012, 2013), although this pattern was not always replicated (van Hemel-Ruiter et al., 2011; Pieters et al., 2012). As these studies have all focused on either working memory or response inhibition, there is little empirical evidence to argue why one or the other should be more important in the interplay with automatic processes in alcohol use. In the domain of eating behavior, it was shown that both working memory and response inhibition independently moderate the relation between automatic valence associations and candy consumption (Hofmann et al., 2009), but this finding has yet to be replicated in context of alcohol use. Similarly, different automatic cognitive biases have been studied (i.e., positive alcohol associations, alcohol approach associations, and approach action tendencies), but rarely in conjunction. While theoretically these constructs are expected to be related (Wiers et al., 2007), this is not consistently supported by research (e.g., van Hemel-Ruiter et al., 2011; Lindgren et al., 2013; Thush et al., 2007; van den Wildenberg et al., 2006), possibly due to the limited reliability of implicit (reaction time) measures. In sum, there is evidence that the relationship between automatic processes and alcohol use is moderated by executive functions, but it is unknown to what extent different indicators of automatic biases and executive functions uniquely contribute to the prediction of alcohol use.

The interplay between executive functions and controlled processes has also been studied, although research in this area has largely focused on alcohol expectancies and less on the role of motivation to restrain. The aforementioned study by Thush and colleagues (2008) found a moderating effect of working memory capacity in the expected direction: Explicit alcohol expectancies were predictive of alcohol use in at-risk adolescents with higher but not in those with lower levels of working memory capacity. In contrast, 2 recent studies in large student samples have found little to no evidence for the expected interactions between alcohol expectancies and cognitive functions (Lavigne, 2013; Littlefield et al., 2011), thereby countering the predictions made by dual process models. It has to be noted that these studies, as well as those studying the moderation of automatic processes, have been conducted in (at-risk) adolescents and (heavy drinking) students, who are likely to have experienced relatively few negative consequences of their alcohol use and are therefore expected to have less negative expectancies regarding the effects of drinking alcohol and less motivation to restrain compared to individuals who are already experiencing alcohol use problems (Jones and McMahon, 1998).

Only a few studies have attempted to test the joint contribution of automatic biases, executive functions, and motivation to restrain (Ostafin et al., 2008; Sharbanee et al., 2013; Tahaney et al., 2014). An experimental study in heavy-drinking adults found that positive alcohol associations were more predictive of alcohol use during a taste test after performing a task that depleted cognitive recourses, than after a control task requiring little cognitive effort (Ostafin et al., 2008). Importantly, all participants were given a situational incentive to restrain their alcohol use, consistent with the assumption that the interplay between automatic processes and executive control only becomes apparent when individuals are motivated to exert control over their impulses. Recently, this assumption was explicitly tested in a heavy-drinking, largely student sample (Tahaney et al., 2014). As expected, it was found that the interaction between appetitive responses and executive functions predicted real-life alcohol use in individuals with high, but not in those with low levels of restraint. However, instead of using automatic biases as a measure of appetitive reactions to alcohol, this study assessed participants' explicit response to being exposed to alcohol (i.e., the urge to drink, and the anticipated stimulant effects of drinking). It is unclear whether these findings generalize to automatic processes, as the relation between automatic biases and explicit craving or expectancies tends to be small (Reich et al., 2010), although likely strengthened by cue exposure (Field et al., 2009). Furthermore, it remains to be seen whether the same pattern would be observed in problem drinkers who are motivated to change. As the level of alcohol-related problems increases, motivation to restrain is thought to increase (Wiers et al., 2007). At the same time, executive functions are expected to weaken, while automatic biases are thought to strengthen after prolonged heavy alcohol use. It would therefore be highly relevant—both from a theoretical and from a clinical perspective—to investigate whether the moderating role of executive functions and motivation also holds for problem drinkers.

This study aimed to answer this question by examining these interactions in a large sample of adult problem drinkers seeking online help to change their alcohol use. We hypothesized that executive functions would moderate the relationship between automatic associations and drinking and that this effect would be stronger in individuals with strong motivation to change. More specifically, we expected that alcohol use would be predicted by the interactions between (i) automatic valence associations, working memory, and motivation; (ii) automatic valence associations, response inhibition, and motivation; (iii) automatic approach associations, working memory, and motivation; and (iv) automatic approach associations, response inhibition, and motivation.

MATERIALS AND METHODS

Participants

Participants were seeking online help in the form of cognitive bias modification and were recruited through newspaper articles, a television documentary on cognitive bias modification, the Addiction Development and Psychopathology (ADAPT) Lab website, the *DrinkingLess* website (Riper et al., 2008), and word of mouth communication with existing participants. In total, 689 participants completed the consent form (see Fig. 1 for the flow of participants through the study). Participants had to meet the following inclusion criteria to be included in the study: (i) an Alcohol Use Disorders Identification Test (AUDIT; Babor et al., 2001) score >7; (ii)

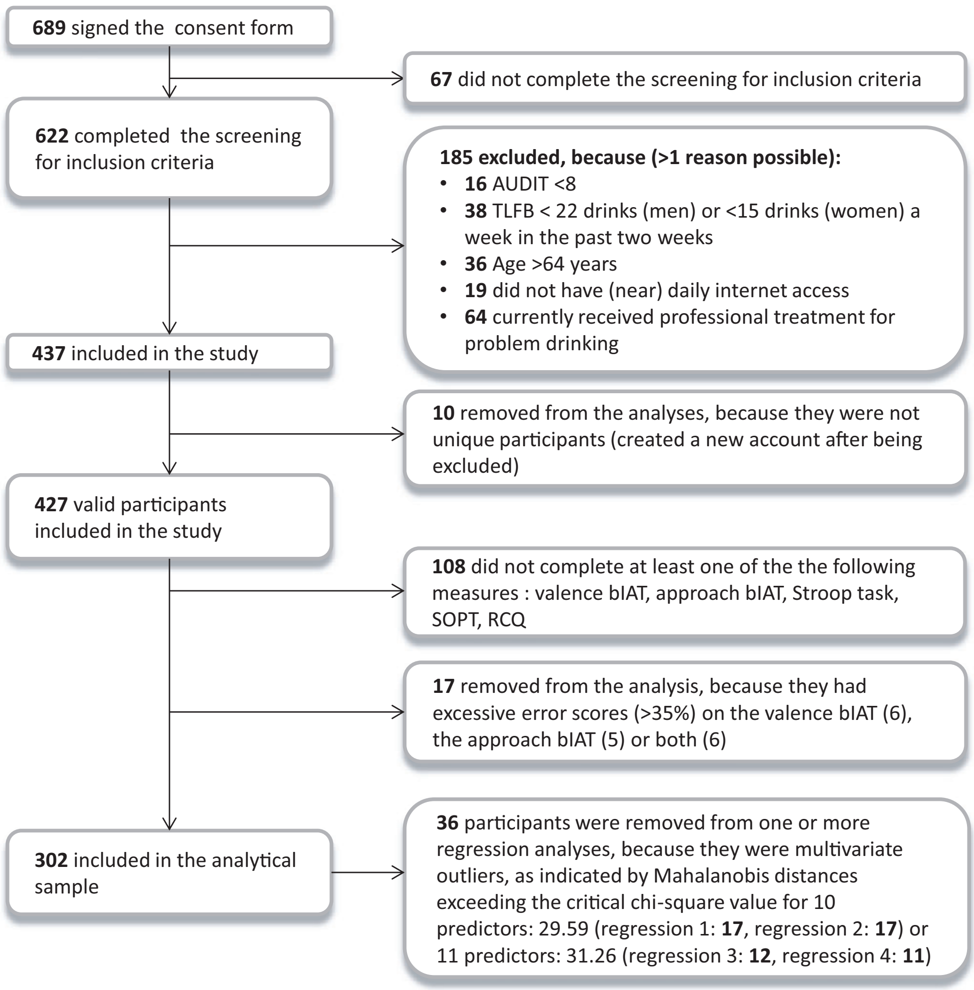

Fig. 1. Participant flowchart.

alcohol consumption of >21 (men) or >14 (women) standard drinks (containing 10 g of ethanol) a week in the past 2 weeks, as assessed with an adapted version of the Timeline Follow-Back (TLFB; Sobell and Sobell, 1992) method; (iii) age between 18 and 64 years; (iv) Internet access; and (v) no professional treatment for problem drinking at the start of the study. A total of 427 problem drinkers who wanted to reduce their alcohol use met the inclusion criteria. The study was approved by the Ethics Committee of the psychology department of the University of Amsterdam and registered at the Netherlands Trial Register (NTR3875).

Measures

This study used the baseline measurement of a larger research project on the efficacy of cognitive bias modification (for an overview of all measures, see van Deursen et al., 2013).

Self-Ordered Pointing Task. A computerized version of the self-ordered pointing task (SOPT; Petrides and Milner, 1982) was used to assess working memory capacity. Participants were presented with a grid of pictures of concrete objects and were instructed to click on each picture just once. After every click, the location of the pictures changed, and participants could not click on the picture that appeared at the location of the previous picture they selected. The task consisted of a practice block of 4 pictures, and 5 test blocks with 6, 8, 10, 12, and 12 pictures. The outcome measure was the total number of correctly selected pictures during the test blocks, ranging from 5 to 48, with higher scores indicating better working memory capacity. This measure has been shown to have good test–retest reliability, $r = 0.82$ (Ross et al., 2007).

Stroop Task. The Stroop task was used to assess response inhibition (MacLeod, 1991). Participants had to indicate the color of a cue presented in the middle of the screen as quickly as possible by pressing the e (red), f (yellow), j (green), or i (blue) key on the keyboard. The task started with a practice block of 40 trials. The next block was an alcohol Stroop of 56 trials, which was not used in this study. The final block consisted of the classical Stroop of 56 trials, with 8 congruent trials (e.g., red in red), 24 incongruent trials (e.g., red in green), and 24 neutral trials (e.g., %%% in green). The outcome measure was the difference score between mean response times on incongruent minus neutral trials, with higher scores indicating more Stroop interference and poorer response inhibition. The current version of the task was found to have acceptable test–retest reliability, $r = 0.73$ (Peeters et al., 2013).

Brief Implicit Association Test. Two versions of the brief Implicit Association Test (bIAT; Sriram and Greenwald, 2009) were used to measure valence and approach associations with alcohol. Participants had to indicate whether the word presented in the middle of the screen belonged to 1 or 2 categories at the top of the screen, by pressing the designated “yes” or “no” buttons on the keyboard. As in the study of Menatti and colleagues (in press), the 7-block structure of the IAT was maintained, but with fewer trials per block. This bIAT version was found to have good internal consistency, with Cronbach's alphas ranging from 0.73 to 0.79. In the first block of the valence bIAT (12 trials), alcoholic (wine, beer, vodka) or nonalcoholic drinks (coke, water, juice) had to be classified as either belonging to the category "alcohol" or not. In the second block (12 trials), words had to be classified as either pleasant (funny, cheerful, sociable) or not (nauseous, sad, tired). In the third (12 trials) and fourth (24 trials) block, the target (alcohol) and attribute (pleasant) categories were combined. In the fifth block (12 trials), the opposite attribute category, unpleasant, was practiced and then combined with the target category (alcohol) in the sixth (12 trials) and seventh (24 trials) block. The approach bIAT (Palfai and Ostafin, 2003) followed the same structure, with the attributes "approach" (grab, touch, take) and "avoid" (let go, avert, ignore). The order of the 2 bIATs was randomized over participants, as well as the order of the combined blocks (but if the valence bIAT started with the alcohol-pleasant block, the approach bIAT always started with the alcohol-approach block and the other way around), and correct response–key combination (yes = i and no = e or vice versa). The outcome measure was the standardized difference in latencies (D600 score) between the different combined blocks (Greenwald et al., 2003).

Self-Report Measures. The Readiness to Change Questionnaire (RCQ; Defuentes-Merillas et al., 2002) was used to assess participants' motivation to change their alcohol use. Participants indicated to what extent they agreed with 12 statements, reflecting the precontemplation (e.g., "It's a waste of time thinking about my drinking"), contemplation (e.g., "My drinking is a problem sometimes"), or action stage (e.g., "I am trying to drink less than I used to"). In addition to assigning participants to a stage of change, a total score ranging from 12 to 60 was computed by reversing scores on the precontemplation items, which has been shown to have good internal consistency ($\alpha = 0.85$; Budd and Rollnick, 1996). Note that the RCQ was administered after a set of questionnaires on which participants received personalized feedback, with the aim of motivating participants for the intervention (i.e., a second assessment of the TLFB and AUDIT, and a questionnaire on the perceived pros and cons of drinking alcohol. These questionnaires were not used in this study). This may have increased participants' motivation to change.

The TLFB (Sobell and Sobell, 1992) method was used to measure participants' alcohol use in the past 14 days. Participants indicated the number of standard alcoholic drinks they drank on each of the specified days, using drop-down menu ranging from 0 to 40. The number of alcoholic drinks per day was then added to compute the total alcohol use over the past 2 weeks.

The AUDIT (Babor et al., 2001) was used to measure participants' alcohol-related problems in the past 12 months. The questionnaire consisted of 10 items and scores ranged from 0 to 40.

Procedure

The study was entirely completed online. After creating an account with their email address, participants were first informed about the goals and the contents of the study. A copy of this information letter was automatically emailed to participants and included information on how to contact the researchers by email or telephone in case they experienced technical difficulties or if they had any questions regarding the study. Contact details were also included in an overview of frequently asked questions, a link to which was shown before the start of every new measure. As the reaction time tasks were not suitable for use on smart phones, participants could only complete the study on a PC or laptop. After giving online informed consent, participants first filled out a brief automated screening for eligibility, including the TLFB and the AUDIT. Participants who were included in the study then completed the 2 versions of the bIAT, the Stroop task, and the SOPT, in random order. The RCQ was administered last. In total, the assessment took approximately 75 minutes to complete.

RESULTS

Sample

Due to missing data ($n = 108$) and excessive errors ($n = 17$), the analytical sample consisted of 302 participants (see Fig. 1 for participant flowchart). Characteristics of the sample are shown in Table 1. Participants had a mean age of 51.7 years (SD = 8.4), and about two-thirds were female (64.9%). On average, participants drank 83.6 (SD = 43.0) alcoholic drinks during the past 14 days, which equals almost 6 standard units per day. The mean AUDIT score was 23.1 (SD = 6.2), suggesting likely alcohol dependence (Babor et al., 2001). Men drank more than women $t(143) = 5.51$, $p < 0.001$. Based on the RCQ, all participants were in the contemplation (84.8%) or action (15.2%) stages of change, which corresponds with the fact that they were seeking help to change their alcohol use. At group level, participants' Stroop scores significantly differed from 0, confirming Stroop interference, $t(301) = 20.66$, $p < 0.001$. Participants' D600 scores on the valence bIAT were not significantly different from 0, $t(301) = 1.83$, $p = 0.069$, indicating no difference in the strength of participants' positive and negative valence associations with alcohol. Participants did on average show relatively strong approach compared to avoidance associations with alcohol: D600 scores on the approach bIAT were significantly greater than 0, $t(301) = 12.62$, $p < 0.001$. As the D600 scores of both the valence, $t(300) = 0.866$, $p < 0.001$, and the approach, $t(300) = 0.688$, $p = 0.008$, bIAT depended on the order of the blocks within the task (alcohol-pleasant/approach first, or alcohol-unpleasant/avoid first), block order was included in the analyses. The order in which the 2 bIAT versions were administered only significantly influenced the approach bIAT, $t(300) = 5.485$, $p = 0.027$, and was only included in analyses involving this task. Neither of the bIAT scores was affected by the key–response combination (yes = i and no = e or vice versa).

Internal Consistencies and Correlations

The 2 versions of the bIAT both showed acceptable reliability: The Spearman–Brown corrected correlation between the D600 score of the practice and test blocks was $r = 0.68$ for the valence bIAT and $r = 0.60$ for the approach bIAT. The Stroop interference score had poor ($r = 0.45$) even–odd reliability. The (5 blocks of the) SOPT showed good reliability ($\alpha = 0.76$), the reliability of the RCQ was good ($\alpha = 0.79$), and the TLFB had very high reliability ($\alpha = 0.93$).

Correlations between all study variables are shown in Table 1. There was a strong positive correlation between

Table 1. Means, Standard Deviations, and Pearson Correlations

	1	2	3	4	5	6	7	8
M	51.68	0.06	0.31	49.65	40.28	171.75	83.57	23.06
SD	08.36	0.55	0.42	05.50	04.24	144.49	42.97	06.18
Median	53	0.10	0.30	50	41	166.54	75	24
Minimum	25	−1.52	−1.11	32	11	−416.00	29	9
Maximum	64	1.61	1.38	60	47	661.13	340	40
1. Age	—							
2. Valence bIAT	0.03	—						
3. Approach bIAT	0.04	−0.02	—					
4. RCQ	−0.03	0.04	0.02	—				
5. SOPT	−0.09	−0.12*	−0.01	0.04	—			
6. Stroop	0.01	−0.09	0.04	0.09	0.02	—		
7. TLFB	0.00	0.15*	−0.01	−0.05	−0.01	−0.03	—	
8. AUDIT	−0.06	0.05	0.02	0.23***	0.10	0.03	0.44***	—

*$p < 0.05$, ***$p < 0.001$.
bIAT, brief Implicit Association Test. Positive numbers on the valence or approach bIAT reflect relatively strong positive or approach associations with alcohol. RCQ, Readiness to Change Questionnaire; SOPT, self-ordered pointing task. A positive SOPT score indicates larger working memory capacity. A positive Stroop score reflects more problems with inhibition. TLFB, Timeline Follow-Back; AUDIT, Alcohol Use Disorders Identification Test.

Table 2. Hypothesis 1: Predicting Alcohol Use with the Valence bIAT × SOPT × RCQ Interaction

	Step 1	Step 2	Step 3	Step 4
ΔR^2	0.12	0.04	0.01	0.03
ΔF	18.57	2.98	1.37	8.92
p	<0.001	0.019	0.251	0.003
Variable (β)				
Sex	−0.329***	−0.311***	−0.315***	−0.309***
Age	0.010	0.014	0.016	0.016
Valence bIAT block order		0.060	0.065	0.065
Valence bIAT D-score		0.075**	0.081**	0.083**
RCQ		−0.021	−0.024	−0.040
SOPT		0.053*	0.053*	0.053*
Valence bIAT × SOPT			−0.040	−0.055*
Valence bIAT × RCQ			0.024	0.031
RCQ × SOPT			−0.025	−0.020
Valence bIAT × RCQ × SOPT				−0.084**

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
For abbreviations, see notes for Table 1. Sex was coded as 0 = male and 1 = female.

alcohol use (TLFB) and alcohol problems (AUDIT). Alcohol problems were also positively related to motivation (RCQ), indicating that those with more alcohol problems were more motivated to change their alcohol use. Stronger positive alcohol associations were related to higher alcohol use (TLFB) and poorer working memory (SOPT).

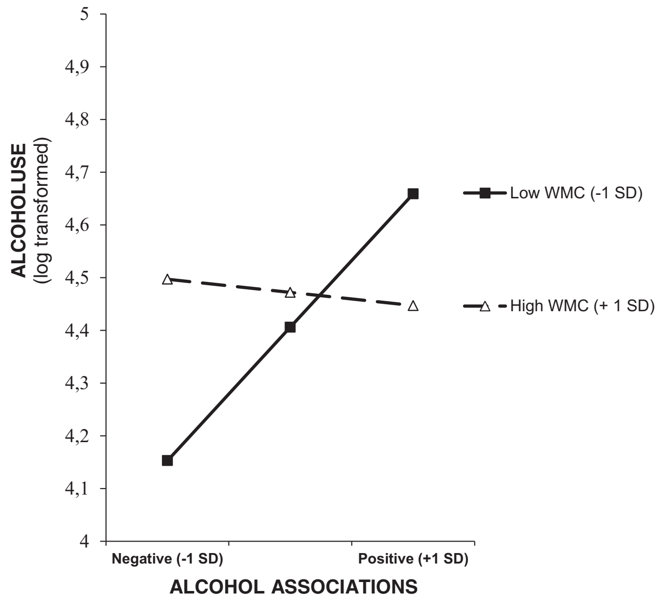

Fig. 2. Relationship between automatic valence associations and alcohol use as a function of working memory capacity, for participants with strong (+1 SD) motivation to change.

Regression Analyses

The 4 hypothesized 3-way interactions were tested in 4 hierarchical moderated regression analyses. The dependent variable was alcohol use in the past 2 weeks (TLFB), which was positively skewed and therefore log-transformed to enhance normality of the data.[1] To arrive at the correct standardized beta weights, all continuous predictor variables were z-standardized and interaction terms were created with these *z*-standardized variables. Multivariate outliers were determined separately for each of the 4 hierarchical moderated regression analyses and were removed only from the relevant analysis (see Fig. 1 for details). At Step 1, age and gender were entered. The relevant individual predictors were added at Step 2: the order of the bIAT blocks and tasks, valence or approach associations (bIAT), motivation to change (RCQ), and inhibitory control (Stroop) or working memory capacity (SOPT). All relevant 2-way interactions between automatic associations, executive functions, and motivation were added at Step 3. At Step 4, the hypothesized 3-way interactions between automatic associations, executive functions, and motivation were added.

[1]The K-S test indicated that TLFB scores differed significantly from normal before, $D(302) = 0.112$, $p < 0.001$, but not after log-transformation, $D(302) = 0.031$, $p = 0.200$.

Table 3. Hypothesis 2: Predicting Alcohol Use with the Valence bIAT × Stroop × RCQ Interaction

	Step 1	Step 2	Step 3	Step 4
ΔR^2	0.12	0.03	0.02	0.01
ΔF	19.90	2.13	2.04	2.24
p	<0.001	0.077	0.109	0.136
Variable (β)				
Sex	−0.339***	−0.327***	−0.320***	−0.320***
Age	0.004	0.004	−0.001	0.002
Valence bIAT block order		0.062	0.056	0.052
Valence bIAT D-score		0.070**	0.071**	0.074**
RCQ		−0.011	−0.014	−0.018
Stroop		−0.015	−0.005	−0.008
Valence bIAT × Stroop			−0.002	0.001
Valence bIAT × RCQ			0.014	0.010
RCQ × Stroop			−0.067*	−0.062*
Valence bIAT × RCQ × Stroop				−0.057

*p < 0.05, **p < 0.01, ***p < 0.001.
For abbreviations, see notes for Table 1. Sex was coded as 0 = male and 1 = female.

Table 4. Hypothesis 3: Predicting Alcohol Use with the Approach bIAT × SOPT × RCQ Interaction

	Step 1	Step 2	Step 3	Step 4
ΔR^2	0.12	0.01	0.02	0.00
ΔF	19.83	0.84	1.99	0.211
p	<0.001	0.523	0.116	0.639
Variable (β)				
Sex	−0.334***	−0.319***	−0.327***	−0.329***
Age	0.011	0.019	0.017	0.018
Approach bIAT block order		0.017	0.022	0.022
Approach bIAT task order		−0.035	−0.024	−0.025
Approach bIAT D-score		0.004	0.005	0.006
RCQ		−0.022	−0.016	−0.015
SOPT		0.045	0.040	0.041
Approach bIAT × SOPT			0.037	0.037
Approach bIAT × RCQ			0.044	0.043
RCQ × SOPT			−0.029	−0.030
Approach bIAT × RCQ × SOPT				−0.015

***p < 0.001.
For abbreviations, see notes for Table 1. Sex was coded as 0 = male and 1 = female.

The first regression analysis tested the interaction between valence bIAT, SOPT, and RCQ (see Table 2). The final model explained 19.2% of the total variance, adjusted $R^2 = 0.16$, $F(10, 274) = 6.49$, $p < 0.001$. Higher alcohol use was related to male sex, positive alcohol associations (valence bIAT), stronger working memory (SOPT), and the 2-way interaction between SOPT and valence bIAT. As hypothesized, alcohol use was significantly predicted by the interaction between valence associations, working memory capacity, and motivation to change. To decompose this 3-way interaction (Aiken and West, 1991), the 2-way interaction between valence associations and working memory capacity was tested separately for individuals with relatively strong and weak motivation to change. Among those with weak motivation (−1 SD), the interaction between valence associations and working memory capacity was not significant ($\beta = 0.028$, $p = 0.429$). Furthermore, an explorative simple slope analysis among those with weak motivation showed no significant relation between valence associations and alcohol use ($\beta = 0.065$, $p = 0.206$). As predicted, however, in those with strong motivation, the interaction between valence associations and working memory capacity was significant ($\beta = -0.139$, $p = 0.001$; see Fig. 2). Simple slope analyses confirmed that in individuals with a combination of strong motivation (+1 SD) and high working memory capacity (+1 SD), valence associations were unrelated to alcohol use ($\beta = -0.025$, $p = 0.633$), whereas in participants with strong motivation (+1 SD) but low working memory capacity (−1 SD), positive alcohol associations were related to higher levels of alcohol use ($\beta = 0.253$, $p < 0.001$).[2]

In none of the 3 other hierarchical moderated regression analyses that were conducted did the addition of the hypothesized 3-way interaction between automatic associations, executive functions, and motivation add to the prediction of alcohol use (see Tables 3–5).

Table 5. Hypothesis 4: Predicting Alcohol Use with the Approach bIAT × Stroop × RCQ Interaction

	Step 1	Step 2	Step 3	Step 4
ΔR^2	0.12	0.01	0.02	0.00
ΔF	19.81	0.31	1.87	0.02
p	<0.001	0.904	0.135	0.876
Variable (β)				
Sex	−0.336***	−0.330***	−0.331***	−0.331***
Age	0.009	0.010	0.006	0.006
Approach bIAT block order		0.025	0.014	0.014
Approach bIAT task order		−0.035	−0.028	−0.028
Approach bIAT D-score		0.003	0.003	0.003
RCQ		−0.007	−0.001	−0.001
Stroop		−0.022	−0.014	−0.014
Approach bIAT × Stroop			0.003	0.002
Approach bIAT × RCQ			0.034	0.034
RCQ × Stroop			−0.058*	−0.058
Approach bIAT × RCQ × Stroop				0.006

*p < 0.05, ***p < 0.001.
For abbreviations, see notes for Table 1. Sex was coded as 0 = male and 1 = female.

DISCUSSION

The results of this study partially support the expected interplay between automatic associations, executive functions, and motivation to change. Main findings can be summarized as follows: First, as hypothesized, motivation to

[2]The hypothesized 3-way interaction between valence bIAT, SOPT, and RCQ was also found when Bonferroni correction was applied to account for multiple testing, when the expected 3-way interactions were tested in 1 hierarchical moderated regression analysis instead of in 4 separate analyses, and when the TLFB data were Winsorized instead of log-transformed.

change moderated the interaction between valence associations and working memory capacity in the prediction of (heavy) alcohol use. Decomposition of the interaction indicated that working memory capacity moderated the relationship between valence associations and drinking in individuals with strong motivation, but not in those with relatively weak motivation. In those with strong motivation but low working memory capacity, positive associations were associated with higher alcohol use. In individuals with both strong motivation and high working memory capacity, positive associations were unrelated to alcohol use. Second, contrary to our expectations, this pattern was not found for other indices of executive functions (i.e., response inhibition) or automatic associations (i.e., approach associations). We discuss these main findings in turn.

The finding that working memory capacity only moderated the relationship between valence associations and alcohol use in those who were strongly motivated is consistent with dual process models (Gladwin et al., 2011; Wiers et al., 2007) and previous research (Tahaney et al., 2014) and suggests that the ability to control one's automatic impulse to drink only becomes relevant when one is motivated to do so. In other words, the combination of both strong motivation and high working memory capacity appears to be required to successfully inhibit the effect of automatic associations on drinking. However, explorative testing in those with relatively weak motivation revealed no significant relationship between valence associations and alcohol use. If both high working memory capacity and strong motivation are required to control the influence of associations on drinking, associations should be related to alcohol use in those with weak motivation.

In contrast to our hypotheses, motivation only moderated the interaction between working memory capacity and valence associations; this effect did not hold for response inhibition and approach associations. A possible explanation for these discrepant results is the fact that the reliability of the measure of response inhibition (Stroop) was poor compared to that of the working memory capacity task (SOPT). As the product of the reliabilities of the individual predictors determines the reliability of an interaction term (Busemeyer and Jones, 1983), this could explain why the only interaction effect that was found included the executive function measure with relatively higher reliability. Furthermore, the limited reliability of the reaction time measures might play a role in the fact that neither the executive function tasks nor the 2 implicit measures were correlated, and limits the conclusions that can be drawn from the (null) results. Aside from the reliability problems, there are 2 other possible explanations for why we did not find most of the expected interactions, the first of which lies in the selection of participants. In contrast to previous research, which investigated the interaction between automatic processes, executive functions, and motivation in participants with relatively low motivation to restrain, the current study set out to investigate this interaction in a sample of problem drinkers with relatively high motivation to change. As excessive alcohol use was also an inclusion criterion, participants were by definition dyscontrolled drinkers: motivated to restrain their alcohol use, yet failing to do so. Naturally, this restricts the possible variability in the studied variables, although the ranges of both motivation and alcohol use were still adequate to examine the hypothesized interactions. Alternatively, it is possible that the factors that contribute to the initiation of (heavy) alcohol use differ from those that maintain problematic alcohol use in the long term, and that the interplay between automatic processes, executive functions, and motivation becomes less pronounced as alcohol use becomes more habitual (Everitt and Robbins, 2005; Vollstädt-Klein et al., 2010). Ideally, future research should include participants with the full range of motivation to change and alcohol use, so that these explanations can be formally tested.

A number of limitations are important to consider when interpreting the results. First, although lack of reliability is a general problem of many reaction time measures (e.g., Schmukle, 2005), several aspects of the design of this study may have negatively influenced the reliability and validity of the measures, specifically (i) the web-based assessment, with little control over how the measures were completed; (ii) the large number of measures, which may have resulted in fatigue; (iii) the fact that the response inhibition measure (classical Stroop task) was preceded by an addiction Stroop task (not used in the current study), which may have caused practice effects and decreased Stroop interference; and (iv) the fact that motivation was assessed after participants received personalized feedback on questionnaires regarding their alcohol use, which is likely to have increased their motivation to change. Notwithstanding these potential concerns, there were also advantages to these aspects of the design. For example, the web-based assessment enabled us to include a large group of problem drinkers, which would have been hard to achieve in a more controlled, laboratory-based setting. A different approach to reduce measurement error could be the use of a latent variable approach, instead of using single indicators of different components of executive functions and automatic associations (Miyake et al., 2000). Another limitation of this study is that about 25% of all eligible participants did not complete all of the measures and were thus removed from the analyses. Although not uncommon during baseline assessments of web-based interventions for problem drinking (Blankers et al., 2011), this may have biased the data in the sense that the participants who dropped out might have been less motivated to change their alcohol use. Other factors that may have contributed to dropout include technical problems and difficulties understanding the task instructions. Participants were repeatedly reminded that they could contact the researchers by email or phone if they had questions or experienced any problems, but it cannot be ruled out that some simply discontinued their participation. A final limitation is that the cross-sectional nature of this study prevents causal conclusions. It would be highly relevant to test these interactions in a longitudinal and/or experimental design, for example, by investigating whether retraining strong automatic processes results in larger decreases in alcohol use in individuals with weak executive functions and strong motivation, compared to those with both strong executive functions and strong motivation. Some steps in this direction have recently been made (Eberl et al., 2013; Houben et al., 2011), for example, in a study on approach bias modification in alcoholic patients, which found larger training effects in older patients, who presumably have lower levels of executive functions.

To the best of our knowledge, this is the first study to examine the joint interplay between automatic associations, executive functions, and motivation in a large sample of problem drinkers. Although the results were not consistent across measures, the finding that motivation interacted with working memory capacity and valence associations suggests that future studies should not overlook the role of motivation when studying the interaction between automatic associations and executive functions. More knowledge about this interplay would enable empirically supported tailoring of interventions for problem drinking.

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CONFLICT OF INTEREST

None.

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