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Is Binge Drinking in Young Adults Associated with an Alcohol-Specific Impairment of Response Inhibition?

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Key Words
Addiction · Binge drinking · Impulsivity · Inhibitory control

Abstract
Background/Aims: Little is known about the association of binge drinking with impulsivity related to trait- or state-like aspects of behavior. The aim of the present study was therefore to investigate whether binge drinkers show an impairment of inhibitory control in comparison to non-binge drinkers when confronted with alcohol-associated or control stimuli, and whether this is reflected in self-reported impulsivity. ***Methods:*** A go/no-go task with pictures of alcoholic and nonalcoholic beverages as well as control stimuli was administered to binge drinkers and a gender-matched group of non-binge drinkers. All participants also completed the Barratt Impulsiveness Scale (BIS-11). ***Results:*** We found an alcohol-specific impairment of response inhibition for binge drinkers only, while the groups did not differ with regard to overall response inhibition to the experimental stimuli or self-reported impulsiveness (BIS-11). In addition, the number of commission errors in response to alcohol-associated stimuli was the only significant predictor of binge drinking. ***Conclusion:*** The findings of the present study suggest that when young adults have established binge drinking as a common drinking pattern, impairment of inhibition in response to alcoholic stimuli is the only significant predictor of binge drinking, but not general impulsive behavior.

Introduction

Recent models of addictive behavior suggest that an impairment of response inhibition and an enhanced salience attribution to alcohol-associated stimuli are two processes that contribute to the development and maintenance of addiction [1]. For example, Boog et al. [2] proposed that rash impulsiveness and reward sensitivity are two aspects associated with addiction. According to this theory, rash impulsiveness reflects disinhibition, 'a rash tendency to act upon acute impulses', and reward sensitivity describes a sensitivity to appetitive rewarding stimuli, which overlaps with the concept and empirical evidence of enhanced salience attribution. In line with this, a large number of studies have demonstrated that heavy drinkers and alcohol-dependent patients show impulsive behavior in questionnaire measures or neuropsychologi-

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cal tasks that assess response inhibition [3–8]. In addition, appetitive responses to alcohol-associated cues have been found with different experimental paradigms using alcohol-associated and neutral stimuli (e.g. modified Stroop tasks, visual dot probe tasks [9]) and imaging methods have been applied to study the brain activity associated with these responses [10, 11].

While these studies primarily investigated the adverse effects of chronic alcohol use, only recently has a growing research interest emerged to assess whether impulsive behavior and impairment of inhibitory control are also associated with binge drinking [12, 13]. Binge drinking is usually characterized as the consumption of large amounts of alcohol in a short time followed by a period of abstinence, as opposed to regular drinking patterns in which a person might consume a similar amount of alcohol per week, but without the extremes of alcohol intoxication [13]. In the United States as well as in European countries, binge drinking is quite common among college and university students and has been associated with negative social and health consequences as well as the development of problem drinking [14]. As adolescence is a critical period of neuromaturation [15] and executive control processes undergo profound development during adolescence [16], binge drinking seems to be especially harmful with regard to the development of cognitive control processes. Thus, several cross-sectional studies demonstrated that binge drinkers compared to non-binge drinkers are impaired with regard to a wide variety of executive functions [13, 17, 18], and especially deficits of response inhibition were shown in several studies [3, 5]. Recently, the results of longitudinal studies using event-related potentials or brain imaging techniques have demonstrated that young binge drinkers show abnormal brain activity during tasks that assess learning and response inhibition without any impairment of behavioral responses [19–21]. Importantly, it has also been demonstrated [21] that some of these abnormalities emerged after only 2 years of binge drinking. These studies support the assumption of the adverse effects of binge drinking on brain development.

However, there are also a number of studies that have demonstrated trait-like impulsive behavior and difficulties in response inhibition might be a risk factor for the development of binge drinking (for a review see [22]). For example, a prospective study [23] found that deficits of response inhibition predicted alcohol-related problems. In addition, several studies demonstrated that children at risk for the development of alcohol abuse show an impairment of response inhibition and less behavioral control [24–26]. Children at risk for alcohol abuse showed disruption in the laterality of the orbitofrontal cortex volume compared to control children and this was associated with genetic variations [26]. In addition, reduced white matter volume in the right orbitofrontal cortex was related to increased impulsivity which might be an antecedent to risky behavior. In line with this, it was reported that automatic alcohol approach tendencies predicted future drinking behavior of young adolescents with relatively weak response inhibition skills [27].

Taken together, there is extensive evidence that the association between binge drinking and an impairment of response inhibition might be reciprocal [28] with impulsive behavior and an impairment of response inhibition contributing to binge drinking, which in turn leads to brain damage and a further impairment of response inhibition. As alcohol-associated stimuli acquire an incentive salience during the development of addictive drinking patterns, this impairment of response inhibition should be especially pronounced when confronted with alcohol-associated stimuli as suggested [1]. There are a few studies [6, 7] that have addressed the question of whether an impairment of response inhibition is especially pronounced when alcohol-associated cues are presented. The findings of these studies indicate that alcohol-dependent patients show an impairment of response inhibition which is enhanced when alcohol-associated cues are presented. However, to the best of our knowledge, up to now only one study has investigated whether binge drinkers also show an impairment of response inhibition which is especially pronounced when responses to alcohol-associated stimuli have to be inhibited. Thus, Nederkoorn et al. [5] administered a modified stop signal task in which neutral as well as alcohol-associated, soft drink, and erotic visual stimuli were presented to participants classified either as heavy versus non-heavy drinkers or binge versus non-binge drinkers. The results of this study indicated that female binge drinkers showed a stronger impairment of response inhibition than the other groups, with no significant differences between the different picture categories. Although these findings are in line with previous studies reporting that female binge drinkers show the strongest impairments of executive function [18], they do not support the assumption of an impairment of response inhibition that is especially pronounced for alcohol-associated responses [6, 7].

The aim of the present study was to enhance our understanding of the nature of the impairment of response inhibition being associated with binge drinking as this might contribute to the development of effective preven-

tion strategies. It was demonstrated that for heavy-drinking young adults, a training in which participants have to repeatedly inhibit responses toward alcohol-related stimuli is effective to reduce excessive alcohol use [29]. However, less is known whether this strategy would also address the needs of binge drinkers. We therefore developed a modified go/no-go task in which stimuli of alcoholic and nonalcoholic beverages were presented and responses to alcoholic beverages had to be inhibited. As a control condition, blocks with geometrical figures were presented. We hypothesized that binge drinkers would show greater response inhibition deficits than non-binge drinkers in response to the geometrical as well as the alcohol-associated stimuli, while we expected a greater impairment of response inhibition to the presentation of alcohol-associated compared to geometrical stimuli for binge drinkers only. We also administered the Barratt Impulsiveness Scale as a trait measure of impulsivity and expected higher self-reported impulsive behavior for binge drinkers. In addition, we calculated a multiple linear regression to assess the predictive validity of trait-like impulsive behavior and impairment of response inhibition with regard to binge drinking. As previous studies reported that female binge drinkers might be especially affected by the adverse effects of alcohol on prefrontal functioning, we included equal proportions of male and female participants in all groups and controlled for gender effects in all analyses.

Material and Methods

Participants

Male and female social drinkers were recruited for this study from the undergraduate and postgraduate population of psychology students of the University of Wuppertal. For study inclusion, participants had to be between 18 and 30 years of age, in good physical health, and be able to fill in questionnaire measures and complete computerized tasks. Participants with alcohol or drug dependence were excluded. Prescreening using a standardized interview was conducted with everyone who responded to the call for participants to check for inclusion and exclusion criteria. Alcohol consumption was assessed with the Alcohol Use Questionnaire (AUQ) [30] and participants who achieved a binge-drinking score of 24 or higher in the AUQ were classified as binge drinkers, while participants with a score equal to or less than 16 were classified as non-binge drinkers [31]. The binge-drinking score is based on the items related to speed of drinking (number of drinks per hour), the 'number of times being drunk in the last six months' and the percentage of times getting drunk when drinking [31]. Participants with a score higher than 16 but below 24 were not included in the study. The study adhered to the Declaration of Helsinki. Student participants received course credits for their participation in the study.

General Procedure

After evaluation of inclusion/exclusion criteria, testing started with the assessment of demographic variables. A questionnaire was then administered to control for current mood [32], and participants also completed the Barratt Impulsiveness Scale (BIS-11) [33] to provide a self-report measure of impulsivity. Then a go/no-go task using visual cues of alcoholic and nonalcoholic beverages as well as geometrical figures was administered to assess behavioral response inhibition. The test session was conducted by a research assistant trained in neuropsychological test administration and lasted about 50 min. All participants were instructed to abstain from the use of illicit drugs for at least 1 week and from the use of alcohol for at least 12 h before the test session to avoid confounding effects of alcohol or drug consumption.

Questionnaire Measures

Alcohol Use Questionnaire. The AUQ [30] was used to assess alcohol consumption of participants and to classify binge versus non-binge drinkers. The questions presented are related to the frequency and amount of alcohol consumption per week in the last 6 months, but also to drinking patterns like the speed of drinking and the frequency of getting drunk (i.e. experiencing loss of coordination, nausea, and/or inability to speak clearly).

Barratt-Impulsiveness-Scale. The German version of the BIS [33] was administered to provide a subjective measure of impulsive behavior in everyday-life situations. This questionnaire comprises 30 items designed to assess general impulsiveness taking into account the multifactorial nature of the construct (e.g. inattention, motor impulsivity, and lack of planning behavior). For the present analysis only the summary score was used as this is the most reliable outcome measure of the German version [33].

Berlin Mood Questionnaire. This questionnaire was used to assess the current mood of participants as this might confound the experimental outcome [32]. A number of 30 adjectives related to different mood states is presented and participants rate on a 5-point Likert scale how much these adjectives describe their current mood (0 = not at all; 4 = very much). Items can be grouped in six different mood states: anger, anxious depression, fatigue, listlessness, high spirits, or engagement.

Experimental Paradigm

Go/No-Go Task. A go/no-go task using visual stimuli that displayed alcoholic beverages, nonalcoholic beverages, or geometrical figures was used to assess impulsive behavior and impairment of response inhibition in response to different stimuli. The task was divided in two parts each lasting about 10 min. In each part, four blocks with alcoholic/nonalcoholic beverages and four blocks with geometrical figures were presented with the sequence of blocks alternating. In the alcoholic/nonalcoholic beverages blocks, visual stimuli of nonalcoholic beverages served as go stimuli and participants were instructed at the beginning of each block to respond as quickly as possible to pictures of nonalcoholic beverages by pressing the space bar. In contrast, participants should inhibit their responses when alcoholic beverages were displayed. In blocks with geometrical figures, a rectangle served as the go stimulus and a circle as the no-go stimulus. At the start of the experimental task, two short practice blocks were presented that were not scored. All pictures were 4 inches high and 6.67 inches wide, and were displayed for 490 ms on a 15.4-inch color monitor of a Lenovo ThinkPad SL510. A total of 40 trials were presented within each block

with 80% of the trials being go trials. After each block there was a short break of 13 s and then a fixation cross was presented for 1,000 ms before the target category for the following block was displayed on the screen.

Before the beginning of the task, 85 pictures of different alcoholic beverages (beer, wine, and spirits) were shown to the participants and they were instructed to select 8 pictures that displayed best their preferred alcoholic beverages. The nonalcoholic beverages consisted of a standard set of 8 pictures displaying softdrinks, water, and juice. After the selection of the alcoholic pictures, participants rated each of the 16 experimental stimuli with regard to liking ('How much do you like this beverage?'), valence ('How pleasant do you find this picture?'), and arousal ('How arousing do you find this picture?'). The analyses of these ratings indicated no significant overall differences between pictures displaying alcoholic or nonalcoholic beverages (all $T \leq 1.49$, all $p \geq 0.15$). However, while binge drinkers and non-binge drinkers did not differ with regard to liking, valence, and arousal of nonalcoholic beverages (all $T \leq 0.67$, all $p \geq 0.14$), binge drinkers achieved higher scores than non-binge drinkers with regard to liking of alcoholic beverages [$t(30) = -2.61$, $p < 0.05$] and rated pictures displaying alcoholic beverages as more pleasant than non-binge drinkers [$t(-2.38$, $p < 0.05$]. In contrast, the groups did not differ with regard to arousal in response to pictures of alcoholic-beverages [$t(30) = -0.52$, $p = 0.61$].

For task presentation and recording of responses we used Presentation® software (Version 16.0, Neurobehavioral Systems Inc., Albany, Calif., USA). As dependent variables, we calculated the number of commission errors (i.e. responses to no-go stimuli) separately for alcoholic/nonalcoholic beverages blocks and geometrical figures blocks.

Statistical Analysis

Differences between binge drinkers and non-binge drinkers with regard to drinking behavior, demographic variables, and affective state were analyzed using t tests, χ^2 analyses, and multivariate analysis of variance. To analyze differences in response inhibition, a repeated measures analysis of variance was calculated for the number of commission errors as dependent variables with *binge drinking* (binge drinker, non-binge drinker) and *gender* (male, female) as between group factors and *category* (alcoholic/non-alcoholic, geometrical) as the repeated measures factor. Data from one participant were excluded from the analysis of response inhibition as the results of an outlier analysis indicated that this participant achieved a commission error score higher than 2 SD above the mean. A univariate analysis of variance was calculated to assess whether binge drinkers and non-binge drinkers and male and female participants, respectively, differed with regard to self-reported impulsivity (BIS-11). In all analyses, the amount of alcohol in grams consumed per week was entered as a covariate to control for a possible confounding effect due to the deleterious effects of the amount of alcohol consumed irrespective of binge-drinking patterns as suggested by Townshend et al. [34]. Effect sizes (partial eta^2) are reported to allow the reader an evaluation of the results given the possibility of lacking significance due to small sample sizes. In addition, a multiple linear regression analysis was calculated to analyze whether the different aspects of an impairment of response inhibition and impulsive behavior are significant predictors of the binge-drinking score. The BIS-11 summary score, the number of commission errors in response to alcoholic stimuli, the number of commission errors in response to geometrical figures and gender, and the interaction effects of gender and the other variables were entered stepwise in the sequence reported here as predictor variables. All analyses were performed with IBM SPSS Statistics Version 20.

Table 1. Demographic and drinking-related characteristics of binge drinkers and non-binge drinkers

	Binge drinkers (n = 16)	Non-binge drinkers (n = 16)
Gender (male/female)	8/8	8/8
Age	22.69±2.50	24.94±3.32*
Binge drinking score (AUQ [30])	30.25±4.34	8.14±4.12*
Grams of ethanol per week	138.91±88.21	35.63±29.04*

Values represent n or means ± SD. * $p < 0.05$.

Results

Participant Characteristics

Sixteen binge drinkers and 16 non-binge drinkers were included in the study with gender being equally distributed in both groups. Further demographic and drinking-related participant characteristics are displayed in table 1. Binge drinkers consumed significantly more grams of ethanol per week [$t(18) = -4.45$, $p < 0.001$] than non-binge drinkers and were significantly younger than non-binge drinkers [$t(30) = 2.17$, $p < 0.05$]. The mean amount of ethanol consumed per week was entered as a covariate in the analyses [30], while age was not related to any of the dependent variables (Spearman correlation: all $r < |0.43|$, all $p \geq 0.11$) and was thus not entered as a covariate. Binge drinkers and non-binge drinkers did not differ with regard to any of the variables of current mood as assessed with the Berlin Mood Questionnaire [$F(6,25) = 0.34$, $p = 0.91$], and none of these variables were significantly related to any of the dependent variables (all $r \leq -0.30$, $p \geq 0.09$ uncorrected).

Behavioral Disinhibition

We found a significant main effect of the repeated measures factor *category* (alcoholic/nonalcoholic, geometrical) [$F(1,26) = 15.34$, $p < 0.05$, partial eta$^2 = 0.37$], which was qualified by a significant category by group interaction [$F(1,26) = 6.51$, $p < 0.05$, partial eta$^2 = 0.20$]. The main effect of group did not achieve significance [$F(1,26) = 2.43$, $p = 0.13$, partial eta$^2 = 0.09$]. As can be

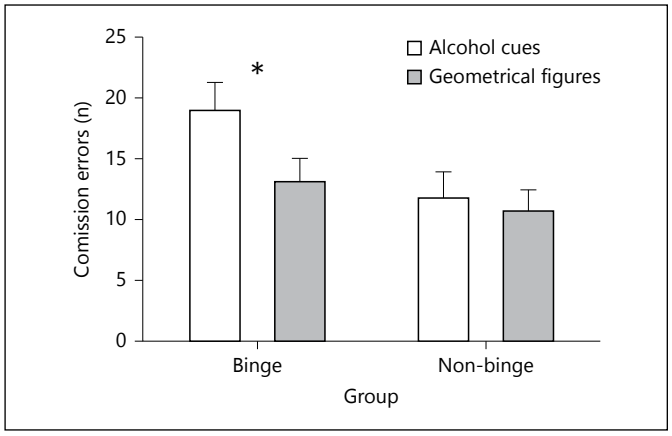

Fig. 1. Binge drinkers committed significantly more commission errors when responses to alcoholic stimuli had to be inhibited (distractors) than when responses to geometrical figures had to be inhibited ($p < 0.05$).

seen in figure 1, these findings indicate that binge drinkers, but not non-binge drinkers, committed more commission errors when responses to alcohol-associated cues had to be inhibited in comparison to control stimuli (fig. 1).

With regard to gender effects, our results indicated neither a significant main effect of gender [$F(1,26) = 1.94$, $p = 0.18$, partial $eta^2 = 0.07$] nor any significant interaction effect ($F \leq 2.46$, $p \geq 0.13$, partial $eta^2 \leq 0.09$). All other main or interaction effects were also not significant (all $F \leq 0.31$, $p \geq 0.16$).

Self-Reported Impulsivity

The results of the univariate analysis of variance indicated that binge drinkers and non-binge drinkers did not differ with regard to self-reported impulsive behavior in the BIS-11 [$F(1,27) = 0.22$, $p = 0.64$, partial $eta^2 = 0.008$]. In addition, this analysis also did not indicate any main or interaction effects of gender (all $F \leq 1.32$, $p \geq 0.26$) with regard to self-reported impulsivity.

Prediction of Binge Drinking

The results of the regression analysis in which we entered self-reported impulsivity (BIS-11), the number of commission errors in response to alcoholic and geometrical stimuli, and gender as predictor variables indicated that the number of commission errors in response to alcohol-associated stimuli was the only significant predictor of the binge-drinking score ($\beta = 0.44$, $t = 2.62$, $p < 0.05$), and accounted for a significant proportion of the variance of the binge-drinking score [$R^2 = 0.19$, $F(1,29) = 6.87$, $p < 0.05$]. All other variables did not achieve significance, and we found no evidence for main effects of gender (all $t \leq 1.50$, all $p \geq 0.15$). However, the interaction effects gender by commission errors in response to alcohol-associated stimuli ($t = 1.83$, $p = 0.079$) and gender by commission errors in response to geometrical stimuli ($t = 1.90$, $p = 0.068$) only slightly failed to reach statistical significance. Given the marginal significance of the interaction effects of gender, separate linear regression analyses were calculated for the male and female participants. The results of these analyses indicated no significant regression model for male participants, while for female participants the number of commission errors in response to alcohol-associated stimuli emerged as the only significant predictor of the binge-drinking score ($\beta = 0.58$, $t = 2.64$, $p = 0.02$), and accounted for a significant proportion of the variance [$R^2 = 0.33$, $F(1,14) = 6.96$, $p < 0.05$].

Discussion

The aim of the present study was to investigate whether binge drinking is associated with an impairment of response inhibition when confronted with alcohol-associated stimuli to enhance our understanding of the nature of response inhibition deficits often reported for binge drinkers [3, 5, 12, 13]. We developed a modified go/no-go task in which stimuli of alcoholic and nonalcoholic beverages were presented and responses to alcoholic beverages had to be inhibited. As a control condition, blocks with geometrical figures were presented. We assumed that binge drinkers would show greater response inhibition deficits than non-binge drinkers in response to the geometrical as well as the alcohol-associated stimuli. In addition, we hypothesized greater impairment of response inhibition to the presentation of alcohol-associated compared to geometrical stimuli for binge drinkers only. Our results indicated in line with our assumptions that binge drinkers, but not non-binge drinkers, committed more commission errors in response to alcohol-associated stimuli compared to control stimuli. However, contrary to our hypothesis, binge drinkers and non-binge drinkers did not differ with regard to the overall number of commission errors in response to the different experimental stimuli, which was also reflected in self-reported impulsive behavior as the groups did not differ in the BIS-11. Thus, in contrast to previous studies that investigated whether binge drinking is associated with a general impairment of response inhibition, we did not find evidence of a deficit of response inhibition irrespective of the con-

tent of stimuli presented. For example, Townshend and Duka [18] found that binge drinkers showed a lack of inhibitory control in the vigilance task from the Gordon Diagnostic System, a task which is similar to a go/no-go task as participants have to inhibit their responses to a cue until the target stimulus appears. In another study it was demonstrated that the number of inhibition failures in a cued go/no-go task with colored rectangles presented either in a vertical or horizontal orientation as go or no-go stimuli was a significant predictor of binge drinking [3]. Thus, it is important to consider task-specific aspects when investigating the association of binge drinking and deficits of response inhibition.

To the best of our knowledge, there has only been one study that previously administered visual stimuli of different picture content to investigate whether binge drinking is associated with an impairment of response inhibition when alcohol-associated stimuli are presented [5]. In this study, Nederkoorn et al. [5] administered a stop signal task and participants had to indicate as quickly as possibly by pressing one of two response buttons whether a picture was presented in a portrait or landscape view. The pictures were taken from four different categories: alcohol, soft drink, neutral (shades of grey), or mild erotic. In 25% of the trials, a stop signal indicated that participants should inhibit their responses. Using the stop signal reaction time as the dependent variable, the results of this study demonstrated no differences in response inhibition between binge and non-binge drinkers, and no content-specific differences in response inhibition emerged. Thus, the results from this study [5] are in line with the present findings as no overall differences with regard to response inhibition deficits were observed between binge drinkers and non-binge drinkers, but in contrast to the present findings there was also no content-specific impairment observed for binge drinkers. There are a number of reasons that might explain these divergent findings. First of all, in a stop signal task, participants are instructed to respond to a stimulus unless a stop signal is presented, but do not need to first categorize stimuli and then to either respond or not as in a go/no-go task. Thus, the two tasks might be related to different cognitive processes which might be differentially affected by binge drinking. Another reason might be that the study by Nederkoorn et al. [5] was primarily designed to assess the association between heavy drinking and response inhibition deficits; the authors report to have decided based on a correlation analysis of the AUDIT score [35], binge drinking score, and alcohol use to use alcohol use as the primary classification criterion and to check the main results for alternative classifications like binge drinking. Thus, we cannot exclude that the binge drinkers of our study differ from those of that previous study [5] with regard to important participant characteristics that might affect the findings (e.g. age, amount of alcohol use not reported separately for binge vs. non-binge drinkers in that study). This is especially important as different criteria were used in these two studies with regard to the classification of binge drinking. While we defined binge drinking based on the criteria developed by Townshend and Duka [31] and relate to 'speed of drinking', the 'number of times being drunk in the last six months', and the 'percentage of times getting drunk when drinking', Nederkoorn et al. [5] classified participants as binge drinkers based on their report of the number of days during the last 2 weeks on which they drank more than 5 units of alcohol on one occasion. This definition seems to be less specific compared to the criteria of Townshend and Duka [31], and the sample of Nederkoorn et al. [5] might also comprise participants with less severe binge drinking patterns.

Our finding of an alcohol-specific, but not general, impairment of response inhibition, is in line with previous studies that investigated whether alcohol-dependent patients show an impairment of response inhibition that is especially pronounced when alcohol-associated compared to control stimuli are presented [6, 7]. The results of these studies are interesting with regard to the findings of the present study. Thus, Noël et al. [6] administered a go/no-go task in which either alcohol-associated or neutral words were presented one after the other rapidly in the center of a computer screen. The words were arranged in 8 test blocks with each block containing 9 alcohol-associated and 9 neutral words. At the beginning of each block, a target category (i.e. either alcohol-associated or neutral) was defined and participants were instructed to respond to words of the target category as quickly as possible by pressing the space bar, but to withhold their response when distracters were presented. As dependent variables, reaction times in go trials and decision bias were calculated taking into account both hits and false alarms. The results of this study indicated that alcohol-dependent patients, compared to healthy controls, committed more commission errors, and a significant group by target interaction was interpreted to indicate that this impairment of response inhibition was pronounced when alcohol-associated words were the targets [6]. Noël et al. [7] and colleagues replicated this finding with alcohol-dependent patients without comorbid substance use and concluded that alcohol-dependent patients show a deficit of response inhibition which is en-

hanced when the responses to be inhibited are related to alcohol. However, the interpretation of these findings has been criticized [36] as the results indicated that when alcohol-associated words were the target category, alcohol-dependent patients inappropriately responded to neutral words, while there seems to be no difference with regard to the response to alcohol-associated words. As Noël et al. [7] also found that alcohol-dependent patients showed longer reaction times when responding to alcohol-associated words as targets than control participants, it was suggested [36] that this finding is more in line with avoidance or an impairment of cognitive processing of alcohol-related words in alcohol-dependent patients. Alternatively, it has been proposed [5] that the findings of Noël et al. [7] might also indicate an overpreparedness of alcohol-dependent patients to detect alcohol-associated stimuli. Based on this criticism of the interpretation of the findings, in the present study we used a modified version of a go/no-go task in which pictures displaying alcoholic beverages always had to be inhibited and pictures of nonalcoholic beverages always served as target stimuli. In addition, our control condition included geometrical figures only. Therefore, we can exclude that our finding of a larger deficit of response inhibition in binge drinkers when alcohol-associated pictures were presented compared to control stimuli is due to avoidance strategies. Thus, it can be hypothesized that binge drinkers show an impairment of response inhibition when alcohol-associated stimuli are presented, while alcohol-dependent patients seem to avoid alcohol-associated stimuli. It would be interesting for future studies to investigate in longitudinal studies if an alcohol-specific impairment of response inhibition changes over the course of time when drinking patterns are changing and problem drinking develops. At present, we only know that impulsive behavior and an impairment of response inhibition are risk factors for the development of problem drinking and addictive behavior [22], and it is assumed that this association is reciprocal as chronic alcohol consumption further impairs cognitive control processes [37].

The results of our multiple linear regression analysis indicated that the only significant predictor of binge drinking was the number of alcohol-specific commission errors. This is an interesting finding as it might indicate that once binge drinking has emerged, state-related aspects of an overall impairment of response inhibition or trait-like overall impulsive behavior do not predict further binge drinking, but instead a specific impairment of response inhibition when alcohol-associated stimuli are presented contributes to binge drinking. It can be hypothesized that such an alcohol-specific impairment of response inhibition is induced by the harmful effects of binge drinking on the adolescent brain, possibly in combination with an increased incentive salience of alcohol-associated cues for binge drinkers. In addition, our results deliver preliminary evidence that gender effects have to be taken into account as we found an interaction effect with gender that slightly failed to reach statistical significance. Separate regression analyses for male and female binge drinkers indicated that the number of commission errors in response to alcohol-associated pictures is only a significant predictor of the severity of binge drinking for female participants. In line with this, there are a number of studies [4, 18] that have found female binge drinkers are more impaired with regard to response inhibition than male binge drinkers or female non-binge drinkers, and it has been hypothesized that binge drinking is especially harmful to the female brain. However, our results with regard to gender should be interpreted with caution as the interaction effect of gender only reached marginal significance and further studies with larger sample sizes are warranted to analyze gender effects.

There are some aspects of the present study that are possible limitations and should be acknowledged when interpreting our findings. Firstly, the sample size of our study was rather small, thus we cannot exclude that differences between the groups with regard to confounding factors that we have not controlled for might have affected our findings. This should be taken into account especially with regard to the nonsignificant or only marginally significant findings with regard to gender effects. Thus, future studies with larger sample sizes are warranted to replicate our findings and to analyze gender effects in more detail. Secondly, we did not assess the smoking status of participants and we cannot exclude that binge drinkers and non-binge drinkers might have differed with regard to smoking. Due to the rather short duration of our test session of only about 50 min, confounding effects due to smoke deprivation seem minimal. However, as shown by Luijten et al. [38], smokers might show a general deficit of response inhibition in comparison to nonsmokers. As our results indicated that binge drinkers compared to non-binge drinkers showed an alcohol-specific, but not general, impairment of response inhibition, confounding effects due to smoking status are unlikely, but cannot be excluded. Thus, future studies are warranted that control for smoking status as binge drinkers might smoke more than non-binge drinkers. In addition, al-

though participants were instructed to refrain from alcohol use 12 h before the test session, we did not control compliance with this instruction, e.g. by means of breath analysis. Therefore, we cannot exclude that binge drinker's performance in the experimental task might have been affected by a hangover or sleep deprivation. Finally, the modified go/no-go task we present here is a new and innovative measure to assess an alcohol-specific impairment of response inhibition, and future studies are warranted to provide more information with regard to reliability and validity of this task. However, the task was derived from methodological considerations and concerns about the interpretation of the results from previous studies [5, 36], and the present findings show promise that this task might be a suitable instrument to address research questions concerning content-specific aspects of response inhibition.

Conclusions

Taken together, the present study has demonstrated that binge drinkers show an alcohol-specific impairment of response inhibition compared to non-binge drinkers, but we did not find evidence for an overall impairment of response inhibition either in self-reported or behavioral measures. Interestingly, in a regression analysis, the number of commission errors in response to alcohol-associated cues emerged as the only significant predictor of binge drinking. In contrast, factors that are supposed to contribute to the development of binge drinking (like an overall impairment of response inhibition or trait-like impulsive behavior) were not significant predictors of binge drinking. Thus, it can be assumed that when young adults have established binge drinking as a common drinking pattern, impairment of response inhibition when confronted with alcohol-associated stimuli is the only significant predictor of binge drinking. Future longitudinal studies are necessary to enhance our understanding of factors that contribute to binge drinking as this is important with regard to the development of effective interventions to prevent it [39].

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Disclosure Statement

All authors report no potential conflicts of interest.

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