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Executive Impairments in Binge Drinking: Evidence for a Specific Performance-Monitoring Difficulty during Alcohol-Related Processing

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Keywords
Binge drinking · Inhibition · Alcohol cues · Performance monitoring

Abstract
This study evaluated inhibition and performance-monitoring abilities through the explicit processing of alcohol cues. Twenty-two binge drinkers (BD) and 22 control participants performed a speeded Go/No-Go task using pictures of alcohol and soft cans as Go and No-Go targets. This task measures inhibitory control and performance monitoring (i.e., task adjustment through errors and feedback processing) during the explicit processing of alcohol cues. Groups did not significantly differ regarding inhibition abilities. However, BD had poorer performance-monitoring abilities, reflected by a difficulty to adjust after errors, especially when these errors were related to alcohol cues. These findings suggest that the explicit processing of alcohol cues negatively impacts cognitive abilities among BD.

Introduction

Binge drinking is an alcohol consumption pattern characterized by the repeated alternations between excessive alcohol intake and abstinence periods [1]. Over the last decade, the consequences of this drinking pattern have been largely explored, binge drinking being related to higher risk-taking during acute consumption (e.g., risky sexual behaviors, injuries, alcohol overdoses) [2], behavioral impairments [3, 4], and anatomical/functional brain modifications [5, 6]. In this perspective, some studies have been conducted to explore similarities between binge drinking and severe alcohol-use disorders, globally supporting the hypothesis of a linear worsening between these 2 consumption patterns [7–9]. Although this proposal still needs direct experimental evidence, binge drinking has been proposed as a first step toward severe alcohol-use disorders [10, 11]. In view of these results, it is crucial to disentangle the specific processes implicated in the emergence and maintenance of binge drinking to better understand the development of alco-

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hol-related problems and tailor prevention and intervention strategies before the appearance of deleterious consequences. In this perspective, executive abilities appear as crucial processes in the understanding of alcohol consumption monitoring. Interestingly, it has been proposed that executive abilities are particularly required when drinkers are confronted with alcohol-related stimuli [12, 13]. This proposal is related to the widely recognized dual-process model, which is considered a reliable theoretical framework to explain the development of excessive alcohol consumption during adolescence and early adulthood [14, 15]. The current study therefore evaluated executive abilities in binge drinking, particularly inhibitory control and performance monitoring, while alcohol cues are presented.

Several studies have indeed explored the processing of alcohol-related stimuli in binge drinking and have shown attentional [16] and interpretative [17] biases, as well as implicit approach tendencies [18] toward alcohol-related constructs. Higher brain activation was also found in response to alcohol cues [19, 20], supporting that a strong reactivity toward alcohol may explain the difficulties encountered by binge drinkers (BD). Regarding executive abilities, specific alterations have been reported for planning [21], flexibility [22], inhibition [23], and decision-making [24]. These results are also supported by evidence of modified cerebral activities, showing higher amplitude of attentional and decisional components during executive processing, which indicates the need for higher cognitive resources to perform such tasks [25, 26]. Among executive abilities, inhibition, defined as the ability to control prepotent responses or disturbing information, has received a great interest as it appears to be directly involved in alcohol consumption monitoring. The inhibition of prepotent response, namely the ability to control an automatic response, has been mainly investigated in binge drinking by using Go/No-Go and Stop Signal tasks. These 2 tasks require that participants respond as quickly as possible to frequent stimuli and inhibit responses to less frequent ones. However, in the Stop Signal paradigm, inhibition is elicited by a specific signal (e.g., a sound), giving indications about the inability to stop an initiated response, whereas in the Go/No-Go task, inhibition is related to a category, rather assessing the inability to prevent response initiation [27]. These tasks thus evaluate different inhibitory processes, a difficulty to stop a response and a difficulty to wait for answering. Although the role of inhibitory control is broadly described in the literature (see [28] for a review), some studies have found no inhibition deficit when BD were compared to a control group with both Go/No-Go and Stop Signal tasks [29]. Similarly, studies have shown that the difficulty to inhibit No-Go trials predicted the number of drinks consumed in one occasion [30], while others have found that alcohol use and problems among BD were not predicted by poor inhibition (assessed by both Go/No-Go and Stop Signal tasks) [31]. Recently, some studies have supported that the relationship between binge drinking and prepotent response inhibition was not straightforward but more thoroughly explained by performance-monitoring deficits, namely reduced adjustment following failures [32], which was also confirmed in case-control studies [33, 34]. Indeed, performance monitoring represents the underlying processes of goal-directed behaviors and can be defined as a continuous checking, allowing the adjustment of the process when needed to ensure the reaching of a specific goal [35]. Performance monitoring can also be evaluated by different paradigms such as Go/No-Go or Stop Signal tasks [33, 34]. Beyond executive control, performance monitoring is thus a crucial ability enabling adapted daily life. Eventually, some findings also indicated that BD present increased motor impulsivity, indexed by a reduced reaction time (RT) in low-level cognitive tasks, compared to matched controls [36, 37]. While quite adaptive when automatic responses are required, motor impulsivity can also explain why BD perform worse (i.e., reduced accuracy scores) in more complex paradigms and thus emphasizes the need for adapted experimental tasks (e.g., speeded ones; [38]) to reliably highlight the difficulties of young adults BD.

Interestingly, some studies have directly explored the ability to control a motor response during alcohol cues processing, either at implicit (no direct alcohol cues processing is needed to perform the task; e.g., alcohol background during inhibition task) or explicit (direct alcohol cue processing is needed to perform the task; e.g., alcohol cues have to be proactively inhibited) levels. Using Go/No-Go paradigms, neuroanatomical and neurophysiological explorations have globally confirmed that BD need more brain resources to inhibit alcohol cues at the explicit level [39, 40], whereas a slower cerebral activity was highlighted at the implicit level [41]. These studies also found behavioral effects indicating lower correct responses rates [39] and more errors in No-Go trials in neutral [40] and alcohol [41] context among BD. Behavioral explorations, however, showed contradictory findings. First, in a Stop Signal paradigm with alcohol, soft drink, erotic, and neutral stimuli, results indicated no effect of implicit alcohol cues among heavy drinkers [42]. Second, during explicit inhibition of alcohol cues compared to neutral objects in a Go/No-Go task, worse performance was found for both problematic and non-problematic young drinkers [43]. Finally, using the same type of task but targeting the specific binge drinking pattern, a study has displayed that BD had impaired inhibition during the explicit processing of alcohol cues but preserved performance when the stimuli used consisted of neutral geometrical forms [44]. Nevertheless, working with more controlled stimuli (i.e., arousing stimuli unrelated to alcohol), a recent research has underlined that BD presented altered inhibition both in neutral and reward context [45]. Actually, these contradictory results might be explained by a lack of control regarding stimuli complexity when comparing alcohol-related and neutral conditions in explicit tasks. Indeed, in most studies, the alcohol condition was compared to a neutral one easier to process [43, 44]. Moreover, it is worth noting that only basic measurements (i.e., RT and No-Go errors) reflecting prepotent response inhibition have been assessed and no research has explored performance-monitoring abilities with tasks directly contrasting alcohol and neutral stimuli.

This study thus aimed at exploring 2 key underlying processes of executive control in binge drinking, namely inhibition and performance-monitoring abilities. Moreover, in line with the dual-process proposal, cognitive abilities were investigated during the explicit processing of alcohol cues. Complementarily to previous studies [43, 44], this research proposed alcohol-related and neutral cues controlled for their complexity in order to obtain directly comparable performance and to specifically determine whether alcohol-related stimuli impact executive abilities and at which processing level (i.e., global inhibition and/or performance monitoring). For this purpose, a validated speeded Go/No-Go task [38] was adapted using alcohol (i.e., beer) and non-alcohol-related (i.e., soft drink) cues. This task was developed to ensure the elicitation of a high number of errors and thus a reliable measure of inhibition and performance-monitoring abilities. Indeed, the task is based on an individually adapted response time limit coupled with the presentation of a "too slow" feedback for slow Go trials, encouraging participants to go faster and increasing the error risk (motor impulsivity). This experimental procedure enabled the assessment of central mechanisms of performance monitoring by obtaining a measure of both errors and feedback adjustment. According to the literature, we hypothesized that BD would have higher difficulties than control participants (CP) when they have to inhibit alcohol cues, and particularly to adapt and regulate their behaviors in an alcohol-related context.

Material and Methods

Participants

Forty-four participants were selected from a preliminary screening according to their alcohol consumption pattern. The binge drinking score [37], considering the consumption speed, the frequency of drunkenness episodes, and the percentage of drunkenness episodes compared to the total number of drinking episodes, was used to categorize students together with classical alcohol-related variables [46]. Importantly, in the current study, an alcohol dose corresponded to 10 g of pure ethanol. The final sample included 22 BD (binge drinking score ≥16, doses per occasion ≥6, doses per hour ≥2, drinking occasions per week between 2 and 4) and 22 CP (binge drinking score ≤12, doses per occasion ≤4, drinking occasions per week ≤4). To take part in this research, students also had to meet the following criteria: fluent French speakers, at least 18 years old, no alcohol-use disorders and no family history of severe alcohol-use disorders, no positive self-reported psychological or neurological disorders, and absence of past or current drug consumption (except alcohol and tobacco). Alcohol use was also evaluated as a control variable to support group differences via the Alcohol Use Disorder Identification Test [47]. Potentially confounding psychopathological variables were evaluated before starting the experiment: anxiety via the State-Trait Anxiety Inventory [48] and depressive symptoms via the Beck Depression Inventory [49]. All participants (56.8% women) were aged between 18 and 26 years (M = 20.93, SD = 2.20). The Ethical Committee of the Psychological Science Research Institute of the University approved this study, which was conducted in accordance with the Declaration of Helsinki, as revised in 2008.

Procedure and Measures

The experiment took place in a single testing session in which an informed consent was first obtained from participants. The experimental task was presented using E-Prime 2 Professional® (Psychology Software Tools, Pittsburgh, PA, USA). Questionnaires were administered (LLC, Qualtrics Software) after the experimental task. At the end of the experiment, participants were debriefed and received a compensation for their participation (EUR 10). Each session was administrated with a maximum of 3 participants simultaneously in a quiet room with separate testing boxes.

A speeded Go/No-Go task, previously validated [38], was used with alcohol-related stimuli. In this experiment, visual stimuli were neutral (i.e., grey), alcohol (i.e., beer), and non-alcohol (i.e., soft drink) cans presented at the center of a white screen (Fig. 1). Alcohol and non-alcohol cans were paired for size, luminosity, and color. Each trial started with a first neutral can (50% of the trials being oriented upward and 50% downward), appearing on the screen center between 1,000 and 2,000 ms, and was replaced at the same central position by an alcohol or soft drink can which could keep the same orientation or have the reverse one. Alcohol or soft drink remained on the screen until the participant responded (on Go trials) or for a maximum of 1,500 ms (on No-Go trials). The inter-trial intervals included a blank screen of 500 ms, followed by a central fixation-cross presented for another 500 ms.

Participants had to respond to Go trials by using the spacebar and refrain from answering in No-Go trials. Two blocks were

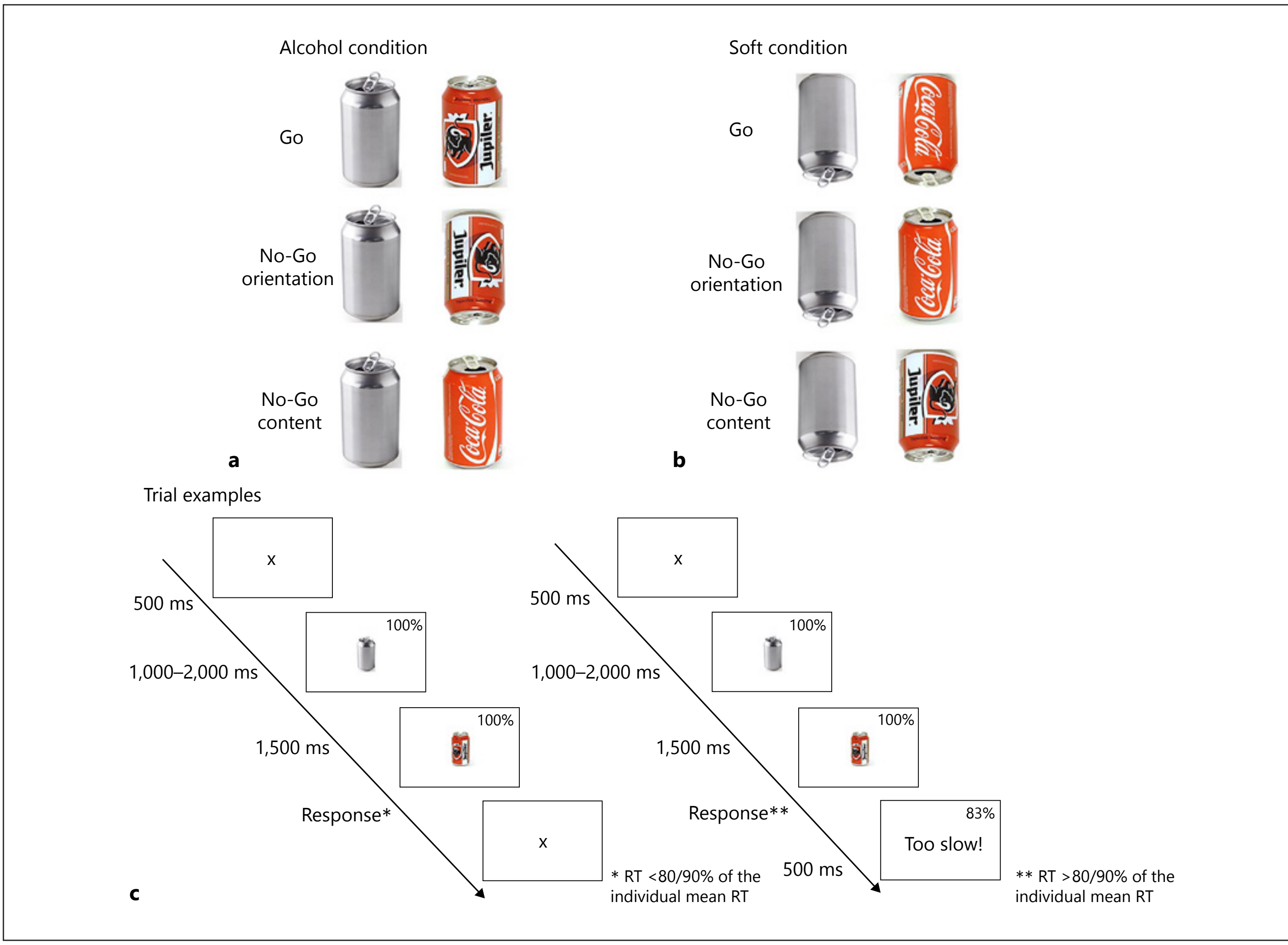

Fig. 1. Speeded Go/No-Go task: Trial examples of (**a**) alcohol condition (illustrated here for the neutral upward orientation), and (**b**) soft condition (illustrated here for the neutral downward orientation). The neutral can was followed either by a congruent stimulus (i.e., alcohol can for the alcohol condition, soft drink can for the soft condition) in the same orientation (Go trial), by a congruent stimulus in the opposite orientation (No-Go Orientation trial), or by an incongruent stimulus in the same orientation (No-Go Content trial). **c** Temporal attributes of a trial: fixation cross (500 ms), first neutral can (1,000–2,000 ms), target can (until the participant's response or 1,500 ms), and participant's response (i.e., pressing the space bar as fast as possible). In the first example, participants responded to the Go trial before time limit (based on the individual mean reaction time (RT) calculated in the previous calibration block: 80% of the mean RT for the first block and 90% of the mean RT for the second and third blocks) and in the second trial, participant responded to the Go trial after the time limit, a feedback "Too slow" was then presented on the screen for 500 ms. This task was adapted from Vocat et al. [38].

designed according to the drinking content factor, leading to the presentation of 2 main conditions: (1) Alcohol condition, in which participants had to press the spacebar when the alcohol can appeared and kept the same orientation (the Go response focusing on alcohol-related stimuli), thus requiring to inhibit their answer when confronted with the alcohol can in the opposite orientation or soft drink can; (2) Soft condition, in which participants had to press the spacebar when a soft drink can appeared and kept the same orientation (the Go response focusing on soft drink stimuli), thus requiring to inhibit their answer when confronted with a soft drink can in the opposite orientation or alcohol can. The No-Go trials were thus based either on the orientation or the content of the can. The whole experiment contained 6 experimental conditions, namely Go and No-Go answers regarding alcohol or soft drink cues and, for the No-Go trials, the processing was also based either on the content or the orientation of the drinking cue.

The 2 experimental conditions were presented in counter-balanced order across participants. Each experiment was divided into 3 sessions of 120 trials (80 Go, 20 No-Go orientation, 20 No-Go content) starting with a calibration block (14 trials). The task was then ended with a last block of 60 trials. The full task included 462 stimuli, and trials presentation was randomized within blocks. The individual mean RT was computed for Go trials in the calibration blocks and defined the upper limit for responding to the Go trials in the following test blocks. Participants were not informed about this procedure. The upper limit was established to 80% of the participant mean RT for the first block and to 90% of the participant mean RT for the second and third blocks. Participants received a feedback when they were too slow (i.e., "too slow") and during the test blocks, the percentage of correct responses was displayed on the top right of the screen (Fig. 1). However, the task procedure ensured that the "too slow" feedback did not distract participants during the task, as it was presented at the end of a trial, during 500 ms and followed by a fixation cross for another 500 ms, which guaranteed that participants had time to process the feedback and adjust their performance. In the same vein, the percentage of correct responses was displayed in the top right of the screen to avoid capturing participant's attentional resources while still informing about the current performance.

The experimental variables were the RT (in milliseconds) for slow (i.e., correct answers but appearing beyond the time limit previously fixed) and fast (i.e., correct answers appearing in the time interval previously fixed) responses to Go trials, the percentage of No-Go errors for alcohol and soft conditions (i.e., when the participant responded to a No-Go trial), the percentage of No-Go errors for orientation and content changes, and the RT for making these errors. Moreover, as we were particularly interested in performance-monitoring abilities, the following variables were also considered: (a) the post-error slowing for alcohol and soft conditions as well as for orientation and content changes, indicating whether the RT of the Go responses following errors are longer than standard Go responses RT; (b) the post-feedback speeding up for alcohol and soft conditions, indicating whether the RT of the Go responses following the "too slow" feedback is faster than standard Go responses RT.

Preparation of the Data

According to previous studies [38, 50, 51], we computed indexes (i.e., subtraction between 2 experimental conditions) to assess post-error slowing and post-feedback speeding up effects for each participant individually. The post-error slowing effect was computed by subtracting the mean RT of the Go responses following correct Go responses from the mean RT of the Go responses following No-Go errors (i.e., RT of Go responses following No-Go errors – RT of Go responses following correct Go responses). This index reflects the performance-monitoring ability and particularly the ability to adjust after errors, higher subtraction scores indicating better adjustment. The post-feedback speeding up effect was computed by subtracting the mean RT of the Go response with feedback from the mean RT of the Go responses following feedback (i.e., RT of the Go responses following feedback – RT of the previous Go response). This index reflects the performance-monitoring ability and particularly the ability to adjust after feedback indicating a too slow answer, higher negative scores representing higher adjustment. Here, BD and CP performance are compared through the percentage of No-Go errors and the 2 performance-monitoring indexes. A Supplementary Materials section also presents the analyses related to the processing speed for Go responses and No-Go errors. These complementary analyses were conducted to ensure that the 2 groups did not differ in terms of global speed processing and that such differences could not underlie our main results.

Statistical Analyses

Descriptive statistics were computed for the 2 groups and independent samples *t* tests were performed. Mean comparisons were then conducted to explore group differences. First, to investigate inhibition abilities, an analysis of variance (ANOVA) was computed on the percentage of errors during No-Go trials through a 2 × 2 × 2 analysis with Group (BD, CP) as between-subjects factor and content-related condition (Alcohol, Soft) and change-related condition (Orientation, Content) as within-subjects factors. Second, to evaluate performance-monitoring abilities, a 2 × 2 × 2 ANOVA with Group (BD, CP) as between-subjects factor and content-related condition (Alcohol, Soft) and change-related condition (Orientation, Content) as within-subjects factors was performed for post-error slowing (based on the following index computation: mean RT of the Go responses following errors – mean RT of the Go responses following a correct Go response), and a 2 × 2 ANOVA with Group (BD, CP) as between-subjects factor and content-related condition (Alcohol, Soft) as within-subjects factor was performed for post-feedback speeding up (based on the following index computation: mean RT of the Go responses following feedback – mean RT of the Go response with feedback). Post hoc comparisons were performed using 2-tailed *t* tests ($p < 0.05$), separately for alcohol and soft conditions, and adjusted for multiple comparisons using Bonferroni correction (for 2 comparisons per change-related condition [orientation and content], the significant threshold was fixed at $p < 0.025$, corresponding to the classical value divided by the number of tests performed).

Results

Demographic and Psychopathological Measures

There was no significant group difference for age ($t[42] = 1.04$, $p = 0.306$), gender ($\chi^2[1, n = 44] = 0.02$, $p = 0.897$), depressive symptoms ($t[42] = 0.99$, $p = 0.328$), state anxiety ($t[42] = 0.96$, $p = 0.343$), or trait anxiety ($t[38] = 0.89$, $p = 0.380$), thus confirming the correct group matching. Groups, nevertheless, significantly differed regarding alcohol consumption characteristics (Table 1).

Inhibition Abilities (Table 2)

Percentage of No-Go errors: There was no main Group effect ($F[1, 42] = 0.71$, $p = 0.404$, $\eta^2_p = 0.017$) and other interactions involving Group were not significant (see Table 3 for more details).

Performance-Monitoring Abilities (Table 2)

Post-error slowing effect: There was no main Group effect ($F[1, 42] = 0.61$, $p = 0.439$, $\eta^2_p = 0.014$), but a Group × Content-related condition interaction (F[1,

Table 1. Demographic and psychological measures for BD and CP: mean (SD)

Variable	BD (n = 22)	CP (n = 22)
Demographic measures		
Age[ns]	20.59 (1.94)	21.29 (2.43)
Gender ratio (female/male)[ns]	13/9	12/10
Psychological measures		
Beck depression inventory[ns]	4.59 (3.67)	3.55 (3.32)
State anxiety inventory (STAI-A)[ns]	33.91 (8.02)	31.50 (8.63)
Trait anxiety inventory (STAI-B)[ns]	38.18 (6.71)	36.14 (8.47)
Alcohol consumption measures		
Alcohol use disorder identification test*	16.55 (5.33)	5.33 (3.55)
Total alcohol units per week*	28.14 (14.21)	5.05 (4.83)
Number of occasions per week[ns]	2.95 (1.09)	2.81 (2.08)
Number of alcohol units per occasion*	9.45 (2.63)	1.52 (0.61)
Consumption speed (units per hour)*	3.50 (1.01)	1.39 (0.76)

* $p < 0.001$.
BD, binge drinkers; CP, control participants; ns, non-significant.

Table 2. Inhibition (No-Go errors in percent and RT in milliseconds) and performance monitoring (differential indexes, in milliseconds) abilities for BD and CP as a function of the condition for each experimental variable of the speeded Go/No-Go Task: mean (SD)

	Alcohol condition		Soft condition	
	BD	CP	BD	CP
Inhibition				
Orientation No-Go errors	44.55 (27.76)	42.39 (24.07)	49.43 (28.15)	39.66 (28.83)
Content No-Go error	58.07 (24.86)	53.30 (29.42)	56.93 (28.19)	51.93 (22.12)
Orientation RT No-Go errors	328.41 (78.15)	350.22 (79.56)	338.08 (88.07)	344.27 (89.88)
Content RT No-Go errors	317.66 (54.40)	321.51 (51.38)	319.83 (95.13)	327.07 (49.50)
Performance monitoring				
Orientation post-error slowing	21.39 (38.28)	18.12 (40.14)	27.14 (52.23)	24.69 (34.69)
Content post-error slowing	33.04 (27.47)	24.47 (26.61)	13.26 (29.81)	49.06 (31.81)
Post-feedback speeding up	–86.48 (42.65)	–83.64 (34.07)	–69.25 (22.73)	–75.37 (35.40)

The differential index for post-error slowing effect corresponds to the mean RT of Go responses following No-Go errors minus the mean RT of Go responses following correct Go responses.
The differential index for post-feedback speeding up effect corresponds to the mean RT of Go responses following feedback minus the mean RT of previous Go response.
BD, binge drinkers; CP, control participants; RT, reaction time.

42] = 4.61, p = 0.038, η^2_p = 0.099) was found, qualified by a Group × Content-related condition x Change-related condition interaction (F[1, 42] = 5.11, p = 0.029, η^2_p = 0.108), indicating poorer post-error slowing in BD. Moreover, this impaired adjustment following errors is specifically observed when BD had to inhibit alcohol cues (i.e., No-Go errors related to the change of content; t[42] = 3.85, $p < 0.001$), while no difference between groups was observed for No-Go errors related to the change of orientation (t[42] = 0.18, p = 0.855; Fig. 2). Other main effects and interactions are reported in Table 3.

Post-feedback speeding-up effect: There was no main Group effect (F[1, 42] = 0.04, p = 0.841, η^2_p = 0.001) nor other main effects or interactions (Table 3).

Table 3. Main effects and interactions for the analyses on inhibition and performance-monitoring abilities

Effects	Inhibition No-Go errors			Post-error slowing			Post-feedback speeding up		
	F(1, 42)	*p* value	η^2_p	*F*(1, 42)	*p* value	η^2_p	*F*(1, 42)	*p* value	η^2_p
Group	0.71	0.404	0.017	0.61	0.439	0.014	0.04	0.841	0.001
Content-related condition	0	0.982	0	0.66	0.420	0.016	3.87	0.056	0.084
Change-related condition	33.04	<001	0.440	2.59	0.115	0.058	–	–	–
Group × content-related condition	0.27	0.608	0.006	4.61	0.038	0.099	0.48	0.493	0.011
Group × change-related condition	0.08	0.780	0.002	3.45	0.070	0.076	–	–	–
Content-related condition × change-related condition	0.49	0.490	0.011	0.15	0.698	0.004	–	–	–
Group × content-related condition × change-related condition	1.22	0.276	0.028	5.11	0.029	0.108	–	–	–

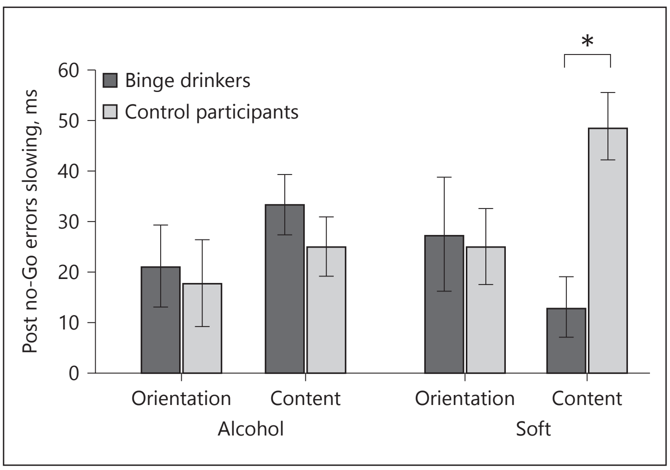

Fig. 2. Binge drinkers (in black) and Control Participants (in grey) results for performance-monitoring abilities. In this task, participants had to perform a Go response based on both orientation and content of the drinking cue. The orientation had to match with the first neutral can presented at the beginning of the trial and the content referred to the nature of the condition, namely, alcohol or soft drinks. This figure represents the mean differential indexes (i.e., mean reaction time [RT] of the Go responses following errors – mean RT of the Go responses following a correct Go response) of the post-error slowing effect for No-Go orientation and content trials for alcohol and soft conditions. Error bars represent the standard error. Results showed that binge drinkers had a reduced post-error slowing effect when they made No-Go errors related to alcohol cues, that is, they were not able to slow down and adjust their performance after alcohol-related errors. * $p < 0.001$.

Discussion

In this research, we tested prepotent response inhibition and performance-monitoring abilities during explicit processing of alcohol-related stimuli in BD and matched controls. To this end, we developed an alcohol-related speeded Go/No-Go task and findings showed impaired adjustment following errors related to alcohol in binge drinking.

At first sight, findings did not confirm inhibition impairments in binge drinking, indicating that BD did not display increased errors in No-Go trials in comparison to CP. This first insight appears surprising in view of earlier studies having evidenced a difficulty to inhibit prepotent responses [23, 45] and a larger motor impulsivity [36, 37] in binge drinking. However, as stated above, the relationship between binge drinking and inhibition seems quite complex and differs according to the experimental paradigm. These results are actually consistent with those of previous research using the original version of the speeded task [33], demonstrating preserved behavioral outcomes but cerebral modifications, potentially aiming at compensating a difficulty to process errors, and therefore inhibiting prepotent responses. Moreover, it seems that explicit alcohol cues processing did not influence inhibition abilities, and this does not support previous results [44], showing a specific difficulty to inhibit alcohol cues. Nevertheless, in the current study, the control condition required to process soft drink cans, ensuring that all stimuli had the same complexity level and hampering that possible inhibition impairment can be merely explained by a complexity effect. Indeed, previous studies showing a deficit for the processing of alcohol cues compared them to neutral stimuli (i.e., geometrical forms or everyday life objects) [43, 44], most probably easier to identify. This assumption is further supported in the present research by the absence of a main content-related condition effect in all analyses. Globally, these results thus suggest that BD have preserved prepotent response inhibition abilities in both alcohol and non-alcohol-related conditions, when these conditions are precisely matched.

Nonetheless, our findings highlight impaired performance-monitoring abilities in binge drinking, observed through the post-error adjustment. Classically, following a No-Go error, individuals slow down their processing in the following Go trials. This post-error slowing effect is an adaptive control mechanism, notably sustained by the anterior cingulate cortex, which allows the adjustment of the processing through a proactive behavioral control, therefore resulting in errors reduction [35, 52]. In the current study, the post-error adjustment is reduced in binge drinking, implying that even if BD are not characterized by deficient motor inhibitory control, in contrast to patients with severe alcohol-use disorders, they present greater difficulty to adequately adjust their behavior and optimize their global performance. These results are consistent with earlier works that emphasized altered performance monitoring in binge drinking [32–34, 53]. This study moreover shows this deficit at the behavioral level, with direct group comparison, and for the first time with an explicit processing of alcohol-related stimuli. Indeed, the current findings indicate that BD failed to adjust when they had to inhibit alcohol cues, and this effect was not observed for the adjustment after No-Go errors related to soft drink cues. Therefore, these findings support the proposal of the dual-process model [13], suggesting that inhibitory control is poorer for the processing of specific affective stimuli (i.e., alcohol-related in binge drinking) due to an interaction between an over-reactivity when processing affective or appetitive cues and a reduced executive control ability. Indeed, this view appears dominant in the literature and has also been proposed to explain binge drinking habits in young people [54, 55]. Besides, the behavioral adjustment after feedback appears correctly performed in BD, which is also in line with previous electrophysiological results [33].

The current research thus clarifies the executive difficulties observed in young BD by targeting inhibitory control and 2 central underlying mechanisms related to performance monitoring (i.e., errors and feedback processing). Findings show that binge drinking is specifically related to poor performance-monitoring abilities, particularly worse No-Go errors adjustment, but preserved inhibitory control. These results should be reinforced by studies especially exploring performance monitoring and errors adjustment, and with larger sample sizes to ensure the representativeness of the sample. Moreover, while BD have been carefully selected, by targeting people with intense and regular consumption pattern, future studies may still improve BD recruitment by taking into account gender differences. In addition to these points, the current study also presents several strengths and implications, as it evaluates executive abilities in binge drinking by a strictly controlled paradigm, offering an explicit processing of alcohol and soft drink cues. First, these results are in line with the dual-process model asserting that addictive disorders are characterized by a difficulty to inhibit approach behaviors toward specific affective stimuli. However, results are not confirmed for global inhibition but for specific performance-monitoring abilities, conveying that compared to patients with severe alcohol-use disorders, BD are rather characterized by impaired abilities to adjust their behavior, a crucial process that can be further implicated in executive control difficulties. Therefore, these findings are in agreement with the assumption of a qualitative continuum between binge drinking and severe alcohol-use disorders [54], by clearly emphasizing difficulties in similar processes but at different quantitative levels. Second, although the cross-sectional nature of the study does not allow drawing causal conclusions, it can be hypothesized that this difficulty participates in the onset and maintenance of alcohol-related disorders. Indeed, poor adjustment after errors is related to a lack of control and could be reflected by a persistence of alcohol consumption despite negative consequences. Moreover, the inability to correctly detect errors and subsequently adjust the behavior could lead to a higher difficulty to inhibit [56], notably with the increase of excessive alcohol use. Finally, this study has clinical implications, at the prophylactic level but also at the therapeutic level. Inhibition training for alcohol cues indeed appears as a very promising intervention notably in young adults young adults [57]. However, future intervention strategies should also specifically target performance-monitoring abilities, notably the basic identification of errors and the subsequent adjustment process.

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Disclosure Statement

All authors report that they have no potential conflicts of interest to disclose.

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