A joint exploration of executive subcomponents in binge drinking

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ABSTRACT

Background: Executive deficits have widely been reported in young binge drinkers over the last decade, but uncertainty remains regarding the specificity of these deficits and their variation across executive subcomponents. The current study aimed to offer a theoretically grounded and specific exploration of the differential deficits observed across executive functions in binge drinkers.

Method: A total of 40 university students (20 binge drinkers: 10 women; 20 matched controls: 12 women) performed three validated neuropsychological tasks, each exploring a specific executive function, namely, shifting, updating, and inhibition (specifically resistance to distractor interference). Tasks were presented to participants in pseudo-randomized order. Repeated measure analyses of variance were performed ~~for each task~~ to compare group performance.

Results: A dissociation was observed across executive tasks regarding group differences: compared with controls, binge drinkers demonstrated preserved performance for shifting and updating abilities, but impaired inhibition. These results support the central role of inhibitory control in excessive alcohol consumption. In contrast to severe alcohol use disorders, binge drinking does not appear to be related to a general executive deficit.

Conclusions: In view of the pivotal role played by inhibition impairments in the emergence of severe alcohol use disorders, these findings suggest that individualized evaluation and rehabilitation programs focusing on this inhibitory control subcomponent may improve control abilities in early stages of alcohol-related disorders.

KEYWORDS Alcohol; executive functions; shifting; updating; inhibition

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Introduction

Binge drinking is a common alcohol consumption pattern in young people, characterized by large alcohol intake in short episodes alternating with withdrawal periods (Courtney and Polich 2009). Research has highlighted that binge drinking is associated with various consequences in the short term (e.g., unsafe sex, injuries; Hingson et al. 2009) and in the long term. Indeed, cognitive impairments related to memory, attentional abilities, and executive abilities have been described (Hartley et al. 2004; Heffernan and O'Neill 2012). Converging data thus highlight that binge drinking is a hazardous alcohol consumption pattern, and it seems crucial to disentangle the specific cognitive processes involved in its emergence and maintenance.

Within this scope, executive functions appear to be core mechanisms, as they have repeatedly been shown to be impaired in patients with severe alcohol use disorders (Brion et al. 2017) and might be involved in the ability to control alcohol consumption (although this causal link remains to be established through longitudinal studies). Executive functions are high-level cognitive abilities that are essential for adaptability in daily life (Diamond 2013). Several conceptualizations have been proposed and the most widely recognized (Miyake et al. 2000) defines three main executive

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processes: *shifting* (the ability to shift back and forth between multiple mental sets), *updating* (the ability to incorporate new information and replace obsolete ~~information~~one), and *inhibition* (the ability to control or regulate one’s behavior). In binge drinking, converging results have reported altered executive functioning characterized by reduced planning abilities (Hartley et al. 2004; Mullan et al. 2011) and lower performance in cognitive flexibility (Salas-Gomez et al. 2016) and attentional flexibility (Scaife and Duka 2009). In addition, several authors have suggested that inhibition represents a key factor in binge drinking (Field et al. 2008). However, inhibition is now considered as a multidimensional construct (Friedman and Miyake 2004) comprising prepotent response inhibition (control of automatic responses), resistance to distractor interference (resistance to disturbance from inappropriate information), and resistance to proactive interference (resistance to memory interference from previously relevant information). This important role attributed to inhibition is mainly related to prepotent response inhibition and supported by studies showing that impaired prepotent response inhibition predicts future excessive drinking (e.g., Carlson et al. 2010; Henges and Marczinski 2012). Research directly comparing young drinkers to controls also confirms that binge drinkers have difficulties in inhibiting automatic response (VanderVeen et al. 2013; Poulton et al. 2016), particularly for alcohol-related stimuli (Czapla et al. 2015). More recently, the role of resistance to distractor interference has also been emphasized in the prediction of binge drinking (Paz et al. 2016). Notably, neuroimaging studies have shown that the brain structure in executive control networks in youth predicted binge drinking in adulthood (Brumback et al. 2016), suggesting that executive difficulties could constitute clear risk markers for the development of substance use before the appearance of behavioral deficits. These neural vulnerabilities were, moreover, observed during inhibition tasks and predicted ~~the onset of~~ binge drinking onset (López-Caneda et al. 2012; Wetherill et al. 2013).

As a whole, while shifting and updating appear to be almost unexplored in binge drinking, research shows that inhibition difficulties are centrally involved in the onset and maintenance of this consumption habit. Nevertheless, earlier studies did not consider the multidimensional aspect of inhibition. Furthermore, previous studies focused on one executive function and did not offer a rigorous comparison across executive subcomponents, thus hampering the determination of whether binge drinking is characterized by a global executive deficit or by specific difficulties. Moreover, beyond the lack of theoretical support, previous work used scattered measures, leading to inconsistencies in the underlying processes involved. For example, flexibility impairments previously reported among binge drinkers (Scaife and Duka 2009; Salas-Gomez et al. 2016) were observed in multi-determined tasks that simultaneously involved working memory, visual-motor speed, and attentional abilities and that have not been confirmed by ~~works~~ studies ~~that~~ isolating~~ed~~ shifting abilities. This underlines the need for an integrated and pure exploration of executive functions.

The current study explores executive functions by comparing binge drinkers to control participants and by separately targeting the three widely recognized executive subcomponents. The aims of this research are twofold: (a) to investigate whether binge drinking is characterized by a global executive deficit or differential impairments, and (b) to extend findings for inhibition and examine the specific role of resistance to distractor interference. To this end, we selected three tasks and presented them in pseudo-randomized order, each evaluating a specific executive process identifiable by using indices computation. For the two first executive functions, we referred to Miyake and colleagues (2000) and selected the most sensitive and representative tasks: the Number Letter task for shifting and the Letter Memory task for updating. For inhibition, the emphasis has been made on resistance to distractor interference (Friedman and Miyake 2004) because this inhibition-related process appears to constitute a predictor of binge drinking but has not been explored by direct group comparisons. We selected the Eriksen Flanker task, identified as the most representative measure of resistance to distractor interference. We hypothesized, in accordance with the literature, that binge drinkers would have ~~great~~significant difficulty in inhibiting distractor interference, with moderate impairments in shifting and updating, processes that have rarely been reported as being altered ~~until now~~.

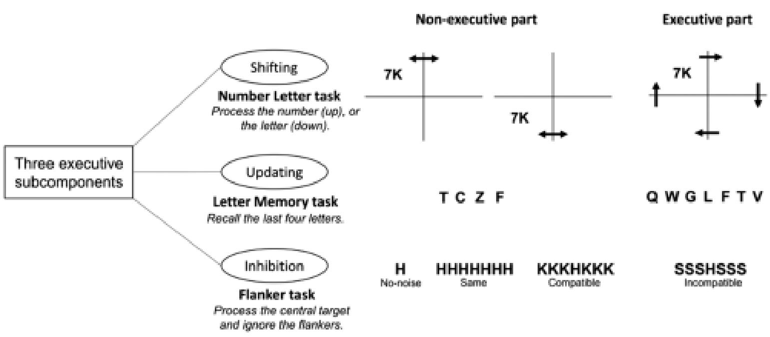
Materials and methods

Participants and procedure

Screening of a large number of participants ($N = 1295$) was first proposed in a university student population to evaluate (a) the binge drinking score (Townshend and Duka 2005) based on consumption speed and drunkenness frequency from the following formula: [(4 × consumption speed) + number of drunkenness episodes + (0.2 × ~~percentage~~percentage of drunkenness episodes among all drinking occasions)]; and (b) other binge drinking criteria (e.g., López-Caneda et al. 2013), namely, the consumption of at least five standard alcohol doses on one occasion (notably two drinks per hour, an alcohol dose corresponding to 10 g of pure ethanol) at a minimum of twice a week. The combination of these criteria allowed us to capture the intensity (number of doses consumed per occasion and binge drinking score) and frequency (number of occasions per week) of the binge drinking pattern. On the basis of this screening, two ~~distinct~~ groups were recruited: 20 binge drinkers (BDs; binge drinking score ≥16,~~;~~ doses per occasion ≥5, occasions per week: between 2 and 4) and 20 control participants (CPs; binge drinking score ≤12, doses per occasion ≤3, occasions per week ≤4). All participants presented a stable consumption pattern for at least 6 months, were French speakers, were between 18 and 30 years old, presented no severe alcohol use disorders and had no family history of severe alcohol use disorders, had no psychological or neurological disorder, were taking no medication~~s~~ that would affect vigilance, had no major medical problem, had no visual impairment, and had no current or past drug consumption. Smokers were excluded, as previous studies have shown the importance of executive functions in nicotine dependence (Flaudias et al. 2016). Information regarding these inclusion/exclusion criteria was collected through self-reported measures during the first screening phase.

The study was conducted in one session in which participants first received basic information about the study and provided written informed consent. They were then tested individually in a quiet room. Questionnaires were administered in paper form and assessed state-trait anxiety (State-Trait Anxiety Inventory; Spielberger et al. 1983), depressive symptoms (Beck Depression Inventory; Beck et al. 1996), impulsivity (UPPS impulsive behavior scale; Billieux et al. 2012), and alcohol-related disorders (Alcohol Use Disorder Identification Test; Babor et al. 2001). The experimental tasks (see Figure 1) were performed by using E-Prime 2 Professional (Psychology Software Tools, Pittsburgh, PA, USA), the order of the tasks being counterbalanced across participants. For each task, the index was calculated in order to isolate the specific executive process, as proposed by Miyake and colleagues (Miyake et al. 2000; Friedman and Miyake 2004). Index calculation consists of subtraction between two experimental conditions having the same requirements in terms of ~~executive~~perceptive, attentional, and motor abilities but differing regarding the specific executive process involved. At the end of the experiment, participants were debriefed and received 10 euros for their participation. The study was approved by the ethics committee of the ~~u~~University and conducted according to the Declaration of Helsinki.

Figure 1 Illustration of the three executive tasks:~~.~~ (a) *The Number Letter task* to assess shifting presents the three possible conditions, the first non-executive part in which participants had to process the number (i.e., the stimulus appears in the upper part), the second non-executive part in which participants had to process the letter (i.e., the stimulus appears in the lower part), and the third executive part in which participants had to process the number or the letter depending on the stimulus position on the screen (i.e., clockwise rotation)~~.~~; (b) *The Letter Memory task* assesses updating, presenting two possible conditions, the first non-executive part in which only four letters were presented successively and the second executive part in which more letters were presented (seven letters in this example) and participants had to recall only the last four letters of the sequence~~.~~; (c) *The Flanker task* assesses inhibition, presenting four possible conditions, the three first non-executive parts, involving no or low interference (No-noise, Same, Compatible) and the fourth executive part (Incompatible) in which participants had to inhibit incongruent flankers to correctly process the central target.



Description of tasks

Number Letter

The Number Letter task assessed shifting abilities. In this task, a number-letter pair (e.g., 7K) was presented in one of the four quadrants (left-up, left-down, right-up, right-down) on the computer screen until the participant responded (or ~~within~~ during 4000 ms). A blank interval of 150 ms appeared between the response and the next stimulus. The participant had to determine, by pressing the corresponding button, whether the number was even or odd when the pair appeared in the upper quadrants, or whether the letter was a vowel or a consonant when the pair appeared in the lower quadrants (i.e., blue button for even and consonant, red button for odd and vowel; the color buttons were counterbalanced left and right between participants). Three parts were successively presented: Non-executive part A (48 trials) consisted of a number categorization task, non-executive part B (48 trials) consisted of a letter categorization task, and executive part C (96 trials) consisted of number-letter pairs that appeared successively in the four quadrants in a clockwise rotation, requiring the participant to shift between number and letter categorization every two trials. The full task comprised 1926 trials and before each part, a preliminary practice of eight trials was presented. The behavioral measures selected were the percentage of correct responses (accuracy score) and the reaction time (RT) for each part (i.e., number, letter, number-letter) as well as a specific shifting index computed for the accuracy score and RT [i.e., (number-letter – (number + letter)/2)].

Letter Memory

The Letter Memory task assessed updating abilities in working memory. This task consisted of the sequential presentation of letters (for 2000 ms) at the center of the computer screen, separated by 500-ms blank screens. After the sequence, the participant had to verbally recall the last four letters of the sequence. Two parts were successively presented: non-executive part A (4 trials, recalling), in which the participant had to recall the four letters presented sequentially; and executive part B (12 trials, updating) in which the participant had to recall the last four letters (without knowing the total number of letters) from trials comprising 5, 7, 9, or 11 letters, thus requiring continuous updating of information (e.g., the first letter had to be replaced by the fifth one in working memory). The full task comprised 16 trials and three preliminary practice trials in which 4, 5, and 7 letters were presented. For this task, the accuracy score was computed from the participant's correct oral responses at the end of a trial (no RT was recorded). The behavioral measures were the percentage of letters correctly recalled in both parts (i.e., recalling and updating) and an updating index (i.e., percentage for updating – percentage for recalling).

Flanker

The Flanker task assessed inhibition abilities. In this task, a horizontal series of seven letters (e.g., SSSHSSS) were successively presented on the screen and the participant had to respond to the central letter as quickly as possible by pressing the corresponding button on the keyboard. The participant was instructed to press the right response key when the target letter was H or K and the left response key when the target letter was S or C. Flankers thus had to be ignored to correctly perform the task. Each trial began with a fixation cross for 500 ms, followed by a blank screen for 1000 ms. The stimuli were presented in black on a white background and remained on the screen until the participant responded. The task included four conditions: (a) no-noise, when only the central target was presented (e.g., H); (b) same, when the flankers were identical to the central target (e.g., HHHHHHH); (c) compatible, when the flankers were different from the central target but associated with the same response key (e.g., KKKHKKK); and (d) incompatible, when the flankers were different from the central target and associated with a different response key (e.g., SSSHSSS). The full task comprised 160 trials (40 trials of each condition) with a preliminary training of 32 trials that presented all conditions. The trial types were presented in pseudo-random order so that the same condition did not occur more than three successive times and there were no negative priming trials (i.e., trials in which the current target letter was the flanker noise letter to be ignored in the previous trial). The behavioral measures selected were the percentage of correct responses (accuracy score) and the RT for each condition, as well as three specific inhibition indices (Friedman and Miyake 2004), computed for the accuracy score and RT [i.e., I-N = (incompatible – no-noise); I-S = (incompatible – same); I-C = (incompatible – compatible)].

Statistical analyses

BDs and CPs were compared for demographic and psychological characteristics. Mean comparisons were then performed for the three experimental tasks that evaluated shifting, updating, and inhibition. First, repeated measures analyses of variance (ANOVAs) were used to compare executive and non-executive conditions between groups for each executive subcomponent separately. Second, indices of the three executive tasks were standardized by using Z-scores and directly compared in a repeated -measure ANOVA. In accordance with the aim of this study (,i.e., assessing group differences regarding executive abilities,), the significant main effects or interactions involving groups were first explored by post hoc independent samples *t*-tests. This procedure allows one to reduce the number of comparisons performed. In the first ANOVAs, post hoc *t*-tests were also computed to compare executive and non-executive conditions within each group. Finally, correlations and regressions were performed to evaluate whether the results observed at the group level were supported by a continuous approach. All correlations between executive performance and binge drinking were assessed. The executive subcomponents that were significantly related to binge drinking were thus added as a predictor of the binge drinking score (dependent variable) in a linear regression model (enter method). Correlations were also performed to evaluate the possible influence of impulsivity.

Results

Demographic and psychological measures

There was no significant difference between groups for age [$t(38) = 1.27$, $p = .21$], gender [$\chi^2(1, N = 40) = 0.40$, $p = .53$], depressive symptoms [$t(38) = 1.22$, $p = .23$], state anxiety [$t(38) = 0.59$, $p = .56$], or trait anxiety [$t(38) = 0.79$, $p = .43$], confirming correct group matching (see Table 1). Moreover, while BDs presented higher sensation seeking than did CPs [$t(38) = 3.16$, $p = .003$], groups did not differ regarding other impulsivity facets [negative urgency: $t(38) = 0.82$, $p = .42$, positive urgency: $t(38) = 1.24$, $p = .22$, lack of premeditation: $t(38) = 1.10$, $p = .28$, lack of perseverance: $t(38) = 1.09$, $p = .28$].

Table 1. Demographic and psychological measures for binge drinkers (BDs) and control participants (CPs).Table Layout

Variable	BDs (*n* = 20)	CPs (*n* = 20)
Demographic measures		
Age	21.60 (1.76)	22.60 (3.05)
Gender ratio (female/male~~)~~	10/10	12/8
Psychological measures		
Beck Depression Inventory	3.60 (3.07)	2.55 (2.31)
STAI state anxiety inventory	32.05 (10.83)	30.30 (7.67)
STAI trait anxiety inventory	39.75 (9.19)	37.70 (6.99)
Alcohol consumption measures		
Alcohol Use Disorder Identification Test*	16.45 (5.41)	3.70 (5.52)
~~Total alcohol units per week*~~	~~26.10 (15)~~	~~1.78 (3.20)~~
Number of occasions per week*	3.50 (1.12)	0.56 (0.84)
Number of alcohol units per occasion*	8.68 (3.59)	1.58 (1.77)
Consumption speed (units per hour)*	3.68 (1.13)	0.61 (0.62)
Note. Values are shown as mean (SD) unless otherwise indicated.		
*$p < .001$.		

Behavioral analyses

Mean performance and RTs for each experimental task are reported in Table 2.

Table 2. Accuracy score (percentage of correct responses) and reaction time (in milliseconds) in each experimental condition of the three executive tasks (i.e., Number Letter, Letter Memory, Flanker) among binge drinkers (BDs) and control participants (CPs).Table Layout

	BDs ($n_1 = 18$, $n_2 = 20$, $n_3 = 20$)	CPs (*n* = 20)
Shifting (Number Letter task)		
Accuracy score Number	91.67 (21.56)	97.19 (3.26)
Accuracy score Letter	92.82 (20.18)	95 (10.97)
Note. For technical reasons, data are missing for two BDs ~~participants~~ in the Number Letter task. n_1 represents the number of participants in the Shifting task, n_2 in the Updating task, and n_3 in the Inhibition task. Values are shown as mean (SD).		

	BDs (n_1 = 18, n_2 = 20, n_3 = 20)	CPs (n = 20)
Accuracy score Number-Letter	89.47 (22.27)	93.75 (7.39)
Reaction time Number	715 (139)	669 (70)
Reaction time Letter	745 (334)	673 (124)
Reaction time Number-Letter	1069 (346)	1077 (202)
Updating (Letter Memory task)		
Accuracy score Recalling	100 (0.00)	98.75 (2.56)
Accuracy score Updating	88.33 (6.64)	86.04 (7.16)
Inhibition (Flanker task)		
Accuracy score No-Noise	98.75 (1.72)	97.38 (3.29)
Accuracy score Same	98.25 (2.31)	98.25 (2.16)
Accuracy score Compatible	99.13 (2.33)	98.88 (1.51)
Accuracy score Incompatible	95 (4.87)	95.38 (4.89)
Reaction time No-Noise	566 (104)	544 (55)
Reaction time Same	535 (83)	526 (55)
Reaction time Compatible	591 (141)	540 (52)
Reaction time Incompatible	600 (99)	569 (62)

Note. For technical reasons, data are missing for two BDs ~~participants~~ in the Number Letter task. n_1 represents the number of participants in the Shifting task, n_2 in the Updating task, and n_3 in the Inhibition task. Values are shown as mean (SD).

Number Letter task

Shifting abilities were evaluated by 2 × 3 repeated measure ANOVAs with Group (CPs, BDs) as the between-subjects factor and Condition (Number, Letter, Number-Letter) as the within-subjects factor, performed separately for the percentage of correct responses and the RT.

The analysis indicated no significant main effects of Condition [$F(2,72) = 1.95$, $p = .15$, $\eta^2_p = 0.051$] or Group [$F(1,36) = 0.69$, $p = .41$, $\eta^2_p = 0.019$] and no Group × Condition interaction [$F(2,72) = 0.62$, $p = .54$, $\eta^2_p = 0.017$] for the percentage of correct responses. A main effect of Condition was found [$F(2,72) = 60$, $p < .001$, $\eta^2_p = 0.625$] for the RT, showing longer RTs in the Number-Letter condition than in the Number [$t(37) = 8.19$, $p < .001$] and Letter [$t(37) = 12.40$, $p < .001$] conditions. However, there was no main Group effect [$F(1,36) = 0.41$, $p = .53$, $\eta^2_p = 0.011$] nor any Group × Condition interaction [$F(2,72) = 0.55$, $p = .58$, $\eta^2_p = 0.015$].

Letter Memory task

Updating abilities were assessed by a 2 × 2 repeated measure ANOVA with Group (CPs, BDs) as the between-subjects factor and Condition (Recalling, Updating) as the within-subjects factor.

The analysis revealed a main effect of Condition [$F(1,38) = 127.31$, $p < .001$, $\eta^2_p = 0.770$], showing a higher percentage of letters correctly recalled in the recalling condition. No main Group effect [$F(1,38) = 2.27$, $p = .14$, $\eta^2_p = 0.056$] nor any Group × Condition interaction [$F(1,38) = 0.23$, $p = .63$, $\eta^2_p = 0.006$] was found.

Flanker task

Inhibition abilities, particularly resistance to distractor interference, were evaluated by 2 × 4 repeated measure ANOVAs with Group (CPs, BDs) as the between-subjects factor and Flanker type (No-Noise, Same, Compatible, Incompatible) as the within-subjects factor, computed separately for the percentage of correct responses and the RT.

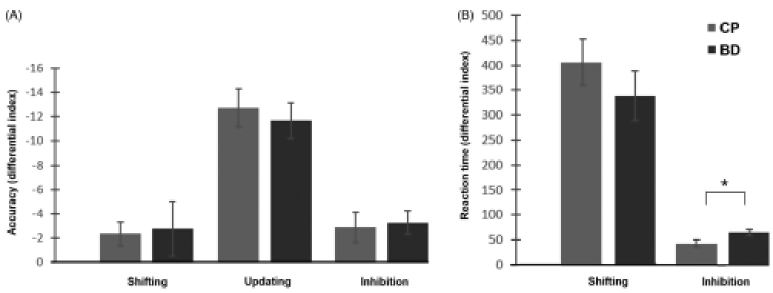
The analysis indicated a main effect of Flanker type [*F*(3,114) = 14.22, *p* < .001, η^2_p = 0.272], showing a reduced percentage of correct responses in the Incompatible condition compared with the Compatible [*t*(39) = 5.32, *p* < .001], Same [*t*(39) = 3.96, *p* < .001], and No-noise [*t*(39) = 3.70, *p* = .001] conditions. There was no main Group effect [*F* (1,38) = 0.25, *p* = .62, η^2_p = 0.006] nor any Group × Flanker interaction [*F*(3,114) = 0.72, *p* = .54, η^2_p = 0.019]. For RT, a main effect of Flanker [*F*(3,114) = 24.32, *p* < .001, η^2_p = 0.390] was qualified by a Group × Flanker interaction [*F*(3,114) = 3.63, *p* = .01, η^2_p = 0.087], showing no direct significant difference between groups with post hoc independent samples *t*-tests (all *p*s ≥ .14). However, it was observed that, in CPs, the Incompatible condition differed significantly from all low interference conditions [Same: *t*(19) = 5.99, *p* < .001; Compatible: *t*(19) = 4.11, *p* = .001; No-noise: *t*(19) = 3.72, *p* = .001]. In BDs, while the No-noise and Same conditions were processed faster than the Incompatible condition [Same: *t*(19) = 9.75, *p* < .001; No-noise: *t*(19) = 5.84, *p* < .001], Compatible and Incompatible trials led to similar RTs [*t*(19) = 0.70, *p* = .49]. There was no main Group effect [*F*(1,38) = 1.14, *p* = .29, η^2_p = 0.029].

Direct comparison between executive functions

To directly compare group performance for the three executive subcomponents, we performed two analyses on the executive indices. For the percentage of correct responses, a 2 × 5 repeated measure ANOVA was conducted with Group (CPs, BDs) as the between-subjects factor and Executive function (Shifting, Updating, I-N inhibition, I-S inhibition, I-C inhibition) as the within-subjects factor. For the RTs, a 2 × 4 repeated measure ANOVA was performed with Group (CPs, BDs) as the between-subjects factor and Executive function (Shifting, I-N inhibition, I-S inhibition, I-C inhibition) as the within-subjects factor.

The index analysis indicated no main Executive function [*F*(4,144) = 0, *p* = 1, η^2_p = 0] or Group ~~effects~~ [*F*(1,36) = 0.20, *p* = .66, η^2_p = 0.005] effects and no Group × Executive function interaction [*F*(4,144) = 0.53, *p* = .72, η^2_p = 0.014] for the percentage of correct responses (see Figure 2). Concerning RT, there was no main effect of Executive function [*F*(3,108) = 0.02, *p* = .99, η^2_p = 0.001] or Group [*F*(1,36) = 0, *p* = .95, η^2_p = 0], but a Group × Executive function interaction was found [*F*(3,108) = 3.10, *p* = .03, η^2_p = 0.079]. Post hoc *t*-tests showed no difference between groups for shifting [*t*(36) = 0.99, *p* = .33], nor for the I-C [*t*(38) = 1.25, *p* = .22] and the I-N [*t*(38) = 1, *p* = .32] inhibition indices. However, a higher I-S inhibition index was observed in BDs [*t*(38) = 2.32, *p* = .03] and indicated inhibition difficulties in this subgroup (see Figure 2).

Figure 2 Executive performance among binge drinkers (BDs) and control participants (CPs). Differential indices for (a) the percentage of correct responses for the three executive subcomponents (i.e., shifting, updating, and inhibition) and (b) the reaction time (in milliseconds) for two of the three executive subcomponents (i.e., shifting and inhibition) among binge drinkers and control participants. Executive indices were computed as follows: Shifting [(number/letter - (number + letter)/2)], Updating (updating – recalling), and Inhibition (I-S = incompatible – same). Poorer performances are represented by lower values for the percentage of correct responses and/or higher RT values. Bars represent the mean for each index and whiskers represent the standard error. The results show that binge drinkers present preserved executive performance according to the percentage of correct responses. However, regarding RT, they present a higher inhibition index, indicating poorer resistance to distractor interference. **p* < .05.



Binge drinking and executive performance

Correlations between executive performance, binge drinking pattern, and impulsivity are reported in Table 3. Analyses supported a specific relationship between inhibition difficulties and binge drinking pattern, particularly for the RT of the I-S index, which was significantly and positively correlated with binge drinking score (*r* = 0.33, *p* = .03), number of doses consumed per occasion (*r* = 0.38, *p* = .01), and consumption speed (*r* = 0.32, *p* = .04). According to these correlational results, the executive subcomponent, showing a significant relation with binge drinking, was the only one included in the regression. A linear regression was conducted to predict the binge drinking score (dependent variable), with the I-S index computed on the basis of RT measures (independent predictor). Findings underlined that the difficulty in resisting distractor interference predicted binge drinking [$F(1,38) = 4.76$, $p = .03$], with an R^2 of 0.111. Regarding impulsivity traits, no significant relationships were found with the specific I-S inhibition index (see Table 3), supporting the reduced influence of impulsivity on the current results.

Table 3. Correlations between executive subcomponents, binge drinking pattern, and impulsivity in the whole sample (*n*~~N~~ = 40).Table Layout

	Shifting		Updating	Inhibition I-C		Inhibition I-N		Inhibition I-S	
	Accuracy score	Reaction time	Accuracy score	Accuracy score	Reaction time	Accuracy score	Reaction time	Accuracy score	Reaction time
Binge drinking pattern									
Binge drinking score	−.10	−.16	.13	−.04	−.03	.08	.27	.03	.33*
Alcohol doses per occasion	−.06	−.12	.11	−.03	−.18	−.10	.18	−.01	.38*
Consumption speed	−.04	−.06	.08	−.09	−.21	−.14	.07	.03	.32*
Impulsivity traits									
Negative urgency	−.17	.37*	.03	.19	−.11	.17	−.14	.31	.05
Positive urgency	−.26	.29	0	.16	.14	.08	−.18	.33*	−.12
Lack of premeditation	.04	−.17	.16	.03	.15	.08	−.10	.15	−.06
Lack of perseverance	−.01	.18	.19	−.05	.17	.03	.07	−.01	0
Sensation seeking	−.20	.11	−.01	−.02	.44**	−.13	−.19	−.12	−.03

Note. $^*p < .05$. $^{**}p < .01$.

Discussion

The present study proposed a joint exploration of executive subcomponents in binge drinking by means of validated neuropsychological tasks that allowed us to specifically explore the three main executive functions (shifting, updating, inhibition). In particular, this study focused on resistance to distractor interference, an inhibition-related process not yet investigated in binge drinking. Results showed that, compared with CPs, BDs were characterized by a differential pattern of executive performance (indexed by RTs), with preserved shifting and updating abilities but difficulties in inhibition.

First, BDs had a higher I-S inhibition index, demonstrating an increased interference effect when processing incongruent flankers. This finding confirms and extends earlier results showing that binge drinking is related to various deficits in self-control abilities. More precisely, beyond the already described impairments for prepotent response inhibition (VanderVeen et al. 2013; Poulton et al. 2016), this study highlights that binge drinking is characterized by difficulty in inhibiting interfering and irrelevant information. It thus appears that BDs need more time to process incongruent distractors and therefore to inhibit and refocus on the central target. The current result is in line with the impaired executive control of attention documented in BDs (Lannoy et al. 2017). Moreover, resistance to distractor interference was previously proposed as a reliable predictor of future binge drinking (Paz et al. 2016), and this study further supports its validity by showing that BDs presented significantly increased processing time compared with that of controls when dealing with interference. Second, while this study is mainly based on ~~computation of~~ indices computation, preliminary analyses were also performed and revealed that BDs had difficulties (i.e., increased RT) in the condition in which flankers were different from the central target, suggesting that they did not take advantage of appropriate information. Indeed, in BDs, the compatible condition had the same difficulty level as the incompatible condition, which was not found in CPs. This suggests that BDs fail to integrate information to correctly perform the task (i.e., paying attention to the nature of the flanker and to the response key to which it refers). By showing difficulties in BDs for low interference conditions, these analyses also clarify that the difference between groups was observed only for the I-S index.

Centrally, the findings did not emphasize difficulties for other executive functions, therefore indicating that when executive subcomponents are specifically explored, BDs present preserved performance for shifting flexibly between two mental categories and incorporating new information in working memory ~~and~~to replace~~ing~~ old information. This highlights that binge drinking is not characterized by general executive difficulty, as was found in severe alcohol use disorders (for a review, see Wilcox et al. 2014). Moreover, this dissociation between inhibition and shifting/updating reinforces the proposal that, besides the correct matching regarding personal variables and comorbidities, BDs and CPs did not differ regarding their global cognitive functioning or motivation, which was also supported by ~~efficient~~elevated accuracy scores in all tasks. Notably, these groups differed only on sensation seeking, thus suggesting a low impact of impulsivity traits, further supported by an absence of a relationship between impulsivity and inhibition. Nevertheless, it appears that the ideal sample size to highlight significant effects with this research paradigm (power of 0.95) is about 70 participants, thus indicating that the current sample size constitutes a limit for these results. In the same vein, results indicated an important variability in the performance of BDs, as shown by the standard deviations, suggesting that although we selected non-overlapping groups according to strict criteria (regarding alcohol consumption but also other influencing factors), performance strongly varied in BDs compared with CPs. Therefore, larger samples would also allow a more comprehensive exploration of the potential factors affecting or modulating executive abilities in binge drinking. Finally, future studies should consider increased sample sizes to evaluate the gender effect. Indeed, while a recent systematic review suggests that there is no strong evidence for gender differences in binge drinking consequences (Carbia et al. 2018), the main differences observed between genders concerned executive abilities (e.g., poorer inhibition in male BDs [Sanchez-Roige et al. 2014] and worse cognitive flexibility in female BDs [Scaife and Duka 2009]). Although it thus seems important to support these findings with a larger sample, it is also worth noting that the sample size (VanderVeen et al. 2013; Czapla et al. 2015) and power (Goudriaan et al. 2007; Petit et al. 2013) of the current work are comparable to ~~several~~most previous studies on this topic. Moreover, we chose to focus on executive functions because they represent crucial abilities, notably in the field of addiction~~s~~, but the current literature reveals an ongoing debate regarding the conceptualizations of executive functions (Friedman et al. 2008; Jewsbury et al. 2016). In this study, we focused on the initial proposal made by Miyake and colleagues (2000) regarding three main executive subcomponents for two reasons: (1) t~~T~~his model is still widely recognized and particularly suitable for comparison with the executive processes explored in binge drinking research until now; and (2) authors of this model have proposed specific experimental tasks, enabling us to purely target each executive subcomponent (i.e., indices computation), which is strongly lacking in binge drinking. However, although this research supports the usefulness of targeting separate executive processes, future studies should strengthen this conceptualization. Finally, the current results should be reinforced with a~~ major~~ deepened exploration of the relationship between binge drinking and executive functions, for example, in multivariate models targeting the three executive subcomponents to predict binge drinking.

As a whole, although these findings need to be confirmed by future work, they already offer new insights into binge drinking research. First, this study offers further support to the differential difficulties across the executive subcomponents proposed by Miyake and colleagues (2000). Second, while resistance to proactive interference remains unexplored, the current results reinforce that inhibitory control is a key process involved in binge drinking. Poor inhibition abilities could indeed reduce control over alcohol consumption (e.g., massive alcohol intake in a short time) and increase the risks associated with excessive drinking. More specifically, it could be hypothesized that impaired resistance to distractor interference is realized through difficulty in inhibiting disturbing alcohol-related concerns, which therefore creates craving, a predictor of future alcohol consumption and binge drinking (Morgenstern et al. 2016). Third, this study has several implications regarding the possible evolution of executive dysfunctions in the course of alcohol-related disorders. The continuum hypothesis, which postulates that binge drinking and severe alcohol use disorders are characterized by similar qualitative deficits, has been supported in terms of executive functioning (Sanhueza et al. 2011). Although it should be confirmed for resistance to distractor interference, the current study helps to specify that the continuum regarding executive functions is particularly obvious for inhibition, as patients with severe alcohol use disorders were also characterized by shifting and updating impairments (Brion et al. 2017). Therefore, inhibition could be the first impaired executive subcomponent in alcohol-related disorders, followed by other executive functions during the chronification of excessive consumption habits. The effects of alcohol in the prefrontal cortex would indeed gradually decrease executive skills. Nevertheless, longitudinal studies are needed to test this proposal and its causal nature from early adolescence to later adulthood, as it appears that brain modifications already exist before the emergence of binge drinking (Brumback et al. 2016). Finally, this study has clinical implications, suggesting that intervention programs that target executive functions (Houben et al. 2011) are warranted, with a particular focus on resistance to distractor interference. Indeed, beyond the group differences, the current study supports the proposal that inhibition difficulties predict future binge drinking.

Conclusion

The current joint exploration of executive functions in binge drinking highlights the differential profiles of deficits and the specific inhibition impairment at the first stages of excessive alcohol consumption.

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