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Component process analysis of verbal memory in a sample of students with a binge drinking pattern

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ABSTRACT

Background: Many studies have emphasized the harmful impact of binge drinking on several cognitive functions, including memory. However, the exact nature of the memory processes involved is still unknown. The present study was designed to assess verbal working memory and verbal episodic memory, especially its encoding, storage and retrieval processes, in binge drinking to identify the processes impacted by this behavior.
Methods: Participants were 48 community-recruited college students aged 18–25 years and categorized as either binge drinkers (BDs) or social drinkers (SDs). They were assessed with (a) subtests of the Wechsler scale (digit span, letter–number sequencing) measuring verbal working memory, and (b) a modified version of the Free and Cued Selective Reminding Test (FCSRT), which measures verbal episodic memory functioning in various conditions of encoding (controlled) and recollection (free recall, cued recall, and recognition).
Results: Verbal working memory was unaffected by binge drinking, whereas verbal episodic memory performances were reduced. In particular, analysis of the modified FCSRT scores suggested that BDs had less proficient storage and retrieval processes. Furthermore, correlational analyses indicated that the proficiency of these memory components was negatively correlated with several indicators of binge drinking behavior.
Conclusions: Results suggest that binge drinking behavior affects the storage and recollection processes of verbal episodic memory. The academic failure described in binge drinkers could be partly related to this harmful effect. Our results on the negative impact of binge drinking on memory should be used to develop information campaigns targeting students.

1. Introduction

Binge drinking has been defined by the NIAAA (2004) as a pattern of drinking that increases blood alcohol concentration to at least 0.8 g/l. This typically occurs with the consumption of four or more drinks for women, and five or more drinks for men in <2 h (on the basis of 14 g of pure ethanol per drink). This problematic pattern of alcohol use has been recurrently described in several countries, especially among young adults, including university students (Krieger, Young, Anthenien, & Neighbors, 2018; Kuntsche, Kuntsche, Thrul, & Gmel, 2017; Tavolacci et al., 2016).

Binge drinking is a major public health concern and has been associated with a wide range of harmful consequences, including elevated risks of physical injury or death, assault, high-risk sexual behavior, and poor academic performances (Kuntsche et al., 2017; Patte, Qian, & Leatherdale, 2017). Furthermore, converging data have stressed the harmful behavioral and cerebral effects of binge drinking, by highlighting several affective or cognitive impairments, including memory (for a review, see Lannoy, Billieux, Dormal, & Maurage, 2019).

Accordingly, alongside research documenting memory impairment among clinical samples of patients with alcohol use disorders (AUDs) (Le Berre et al., 2014, 2017; Pitel, Eustache, & Beaunieux, 2014), numerous

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neuropsychological studies have highlighted the impact of binge drinking on memory (for a review, see Carbia, López-Caneda, Corral, & Cadaveira, 2018), with consistently reduced performances on tests of short- (i.e., working) and long- (i.e., episodic) term memory among young adult binge drinkers (BDs).

Using the spatial working memory task of the Cambridge Neuropsychological Test Automated Battery (CANTAB; Fray & Robbins, 1996), several studies have reported a higher number of errors among BDs, but only for women (Townshend & Duka, 2005; Scaife & Duka, 2009). This gender-specific pattern was also observed in an fMRI study featuring a different spatial memory task, which highlighted reduced activation in several brain areas among female but not male BDs (Squeglia, Schweinsburg, Pulido, & Tapert, 2011). Other studies using digit span and Corsi block tapping tests, which are respectively regarded as measures of the phonological loop and the visuospatial sketchpad in Baddeley's working memory model (Baddeley, 2000), have reported weak performances among BDs (Parada et al., 2012; Sanhueza, García-Moreno, & Expósito, 2011). Furthermore, a longitudinal study showed that performances on the Self-Ordered Pointing Task, a task eliciting a higher working memory load, were weak among ex-BDs, and weaker still among BDs (Carbia et al., 2017a).

Similar results have been observed for episodic memory. Using the Paired Associates Learning test from the CANTAB, Scaife and Duka (2009) showed that BDs made more mistakes and required more stages to complete the first trial of this verbal memory test. Other studies, using either the Rey Auditory Verbal Learning Test (RAVLT), subtests from the Wechsler Clinical Memory Scale (WMS) or the California Verbal Learning Test (CVLT) have shown that BDs exhibit poor performances (Carbia et al., 2017b; Mota et al., 2013; Parada et al., 2011; Winward, Hanson, Bekman, Tapert, & Brown, 2014). The RAVLT revealed sensitivity to proactive interference, as learning a second list was more difficult than the first attempt at learning the first list, while BDs performed more poorly than controls on the Logical Memory subtest of WMS, which requires the learning of two independent stories. As for the CVLT, which requires participants to learn a shopping list of 16 items belong to four semantic categories, it revealed poor immediate cued recall, as well as poor delayed free and cued recall. However, it is worth noting that a 2-year follow-up study showed that participants who abandoned binge drinking exhibited similar performances to controls, suggesting a recovery of episodic memory (Mota et al., 2013).

The deleterious impact of binge drinking on memory therefore appears well documented (even if some studies have failed to detect any impact; see Carbia et al., 2018). However, it should be noticed that in several of the above mentioned studies, the consumption of other substances such as tobacco or cannabis was higher among binge drinkers and thus could have interfere with their memory performance. Likewise, binge drinkers can also exhibit anxiety or depression symptoms which can impact their cognitive performance (Hermens et al., 2013; Nourse, Adamshick, & Stoltzfus, 2017). It would therefore be advisable to control these potentially confounding factors.

Furthermore, the exact nature of the affected cognitive processes is still unknown. Accordingly, classic neuropsychological models of memory suggest that episodic memory functioning is based on three processes, namely encoding, storage, and retrieval (Baddeley, 2000; Tulving, 1995). Encoding corresponds to the process of receiving, processing and combining information, and has been related to working memory abilities, storage corresponds to the retention of the information, and retrieval is the process of recovering information stored in long-term memory and has also been related to working memory abilities. While storage has been related to medial temporal lobe integrity, encoding and retrieval processes have been related to frontal areas of the brain (see, for instance, Eustache & Desgranges, 2008). In patients with severe AUDs, the literature shows that impairment of these three processes is related to the extent of brain damage (Pitel et al., 2014).

The present study was therefore designed to assess working and episodic memory, and to further explore encoding, storage and retrieval processes in binge drinking, in order to characterize the nature of memory deficits associated with this behavior. We decided to focus on a sample of young adult college students, as a large proportion of them are exposed to binge drinking. We also decided to focus on the verbal modality of memory, as it (1) allows material including free and cued recall to be simply constructed, and (2) is more relevant to academic learning than the visual modality. In line with previous studies among BDs, we hypothesized that young adults with a binge drinking pattern are less proficient on verbal working and episodic memory tests.

The impact of binge drinking on memory may well be one of the reasons for the decrease in academic performances observed in students who engage in this behavior. In addition, as has been described in AUDs (Le Berre et al., 2012), this memory deficit may constitute a cognitive barrier, reducing students' motivation to change their drinking behavior by hampering the integration of the negative consequences of binge drinking episodes in memory. Therefore, beyond the recommendation of drinking in moderation, it is important to identify the precise nature of the memory processes affected by binge drinking, in order to better understand the underlying mechanisms and develop effective treatment programs.

2. Material and methods

2.1. Participants

Forty-eight volunteers (20 male and 28 female) were recruited at the University of Reims Champagne-Ardenne (France) on the basis of a short screening questionnaire assessing age, sex, education level, native language, and alcohol consumption. During recruitment, they were assigned to one of two groups: BDs or social drinkers (SDs). The BD classification was based on NIAAA criteria (2004), such that participants who reported one or more binge drinking episodes per month over the previous 6 months were included in the BD group, while participants who reported less than one binge drinking episode per month were included in the SD group. A binge drinking episode was defined as the consumption of 5 standard units (70 g of pure ethanol) or more for a man, and 4 standard units (56 g) or more for a woman within a 2-hour period. Groups were matched on sex, age, and education level.

Inclusion criteria were age $\geq$ 18 years, French native speaker, and non-abstainer of alcohol. Based on self-reported measures, we also ensured that participants reported no alcohol dependence, no psychiatric or neurological disorder, and no visual impairment, and were not on any psychotropic medication. In line with these criteria, two participants who reported daily consumption of alcohol were excluded from the analyses. The final sample consisted of 23 BDs and 23 SDs.

Participants were asked to refrain from drinking alcohol and taking illicit drugs for at least 24 h before the session. They were allowed to smoke as they would normally before the session, but smoking was not permitted during testing. Assessments were conducted in a quiet room.

In accordance with the Declaration of Helsinki, all participants freely gave their formal, written informed consent at the beginning of the study. They were provided with an information sheet setting out the main objectives of the study, and were informed that they could withdraw at any time.

2.2. Measures

2.2.1. Alcohol and other substances use

Alcohol consumption was assessed with two validated questionnaires designed to assess at-risk alcohol use. The Alcohol Use Disorders Identification Test-Consumption Revised (AUDIT-CR; Cortés-Tomàs et al., 2017) measures alcohol consumption frequency, intensity, and the number of drinking episodes in which participants drank more than 4 (women) or 5 (men) alcohol units within two hour. Item 3 was used to classify participants as binge BDs, if they reported at least one binge drinking episode per month over the previous 6 months. The Alcohol

Use Questionnaire (Mehrabian & Russell, 1978) contains items probing the mean weekly number of alcohol units consumed over the previous 6 months (in France, a unit of alcohol is defined as 10 g of pure ethanol), the number of alcohol units consumed per hour (consumption speed), the frequency of intoxication episodes, and the ratio (%) of intoxication episodes to the total number of drinking occasions in the previous 6 months. According to Townshend and Duka (2002), these last three items allow a binge drinking score to be calculated as follows: [(4 * consumption speed) + intoxication frequency + (0.2 * intoxication percentage)]. The binge drinking score complements the AUDIT-CR, by providing additional information on the intensity of binge drinking behavior (Townshend & Duka, 2002).

Tobacco consumption was evaluated by asking participants about their current cigarette smoking and administering the Fagerström test for nicotine dependence (Heatherton, Kozlowski, Frecker, & Fagerström, 1991) to those who identified themselves as current smokers. Cannabis consumption was assessed with the Cannabis Abuse Screening Test (Legleye et al., 2015), a self-report questionnaire developed to screen problematic cannabis use via six items rated on a Likert scale ranging from 0 (Never) to 4 (Very often).

2.2.2. Memory assessment

2.2.2.1. Working memory. Verbal working memory was assessed with two tasks: a digit span task and the Letter–Number Sequencing task. A forward and backward digit span task adapted from the Wechsler Adult Intelligence Scale (Wechsler, 2008) was used to assess auditory spans. In this task, participants are asked to immediately recall increasingly long series of digits given at the rate of 1 digit per second in either the same order (forward condition) or the reversed order (backward condition). In this adapted version, there were a maximum of three trials at each level. The number of digits ranged from 3 to 11 in the forward condition, and from 3 to 10 in the backward condition. A correct answer led to the next level, while an incorrect answer led to another trial with the same number of digits. The task was stopped when a participant failed to answer correctly for the third time in a row. The dependent measures were the maximum number of digits correctly recalled (span) in each condition (forward and backward). The forward digit span is thought to elicit the phonological loop of working memory, and the backward span the phonological loop and central executive. The Letter–Number Sequencing test consists of l0 items, each with a maximum of three trials. In this test, the experimenter reads out mixed lists of digits and letters to participants, who are asked to recall them in ascending numerical and alphabetical order (21 trials). This task involves additional processing requirements similar to those of the digit span. Performance corresponds to the number of correct responses.

2.2.2.2. Episodic memory. Verbal episodic memory was investigated through a modified version of the Free and Cued Selective Reminding Test (FCSRT; Grober & Buschke, 1987; Grober, Ocepek-Welikson, & Teresi, 2009). In the original task, participants are asked to learn 16 words belonging to 16 different semantic categories presented in groups of four cards. Although this task is well suited to investigating memory processes, it is too easy for nonclinical young adults. For this reason, we decided to make it more difficult by adding items. Hence, our modified version was composed of 24 target words belonging to 24 different semantic categories, together with 24 semantic distractors and 24 neutral distractors (i.e., not semantically related to the target words; see Supplemental Table 1). We selected items characterized by their low lexical frequency and their low typicality in the corresponding semantic category (Rosch & Mervis, 1975) from the OpenLexicon database (Pallier & New, 2019). They were pretested among a sample of students ($n = 60$) to ensure that they were familiar (lexical decision task) and were not produced in the first four responses of a semantic association task with superordinate categories as cues (exemplar generation task; e.g., "fruit: apple, pear, banana, etc.").

The material was presented to the participants on a computer screen in four different slides, each comprising 6 words. For each slide, the encoding phase consisted in participants reading each word aloud when its category cue was verbally provided. The slide was then removed, and encoding accuracy was tested by providing the category cue for each of the six words. If there was any error, the encoding procedure was repeated for the unrecalled item(s) until the participant answered correctly. The words that were correctly provided during the first immediate cued recall attempt were summed to yield an immediate cued recall score (0–24). This score reflected encoding proficiency (Grober & Buschke, 1987).

The subsequent recall phase comprised three trials, each preceded by 20 s of backward counting (beginning from 374). Each trial consisted of a period of free recall (up to 2 min), immediately followed by cued recall (category) for the words that had not been retrieved at free recall. Participants were selectively reminded of items missed at cued recall in Trials 1 and 2 by the experimenter, who gave the correct response. This was then repeated by the participant. The words that were correctly and spontaneously provided during the three trials (0–24 for each trial) were summed to yield a free recall score (0–72). This score reflected retrieval proficiency (Grober & Buschke, 1987).

The words that were correctly provided at free or cued recall during the three trials (0–24 for each trial) were summed to yield a total recall score (0–72). After the third cued recall and 20 s of backward counting, participants underwent a recognition phase, when they were shown all 72 words (24 target words, 24 semantic distractors, and 24 neutral distractors) in a fixed random order. The total recall score and the recognition scores reflected storage proficiency (Grober & Buschke, 1987).

In addition, we counted the number of intrusions (words that were not target words) and the number of perseverations (words already provided) during free or cued recall trials. These reflected more general metamemory processes, including self-monitoring (Shindler, Caplan, & Hier, 1984).

2.2.3. Other assessments

The severity of anxiety and depressive symptoms was measured with the short form of the Beck Depression Inventory (BDI-short form; Reynolds & Gould, 1981) and the State-Trait Anxiety Inventory (STAI; Spielberger, Gorusch, Lushene, Vagg, & Jacobs, 1983). The BDI-short form is a self-report questionnaire that assesses the intensity of depressive symptoms via 13 items rated on a 4-point Likert scale ranging from 0 to 3, while the State-Trait Anxiety Inventory is a self-report questionnaire that assesses anxiety symptoms via 40 items rated on a 4-point Likert scale ranging from 1 (No) to 4 (Yes). Reliability for our sample was very good ($\alpha = 0.85$ for the BDI-short form, $\alpha = 0.91$ for state anxiety, and $\alpha = 0.92$ for trait anxiety).

2.3. Data analysis plan

First, we assessed differences between the BD and SD groups on background and verbal memory measures. Chi-square tests were used for categorical variables, and independent t tests for numerical variables. Nonparametric Mann–Whitney U tests were used for numerical variables if the normality assumption was violated, according to the Shapiro–Wilk test.

Next, to investigate the effect of learning across groups we conducted mixed model analyses on the numbers of free and total recall trials of the FCSRT. We first conducted a linear mixed model analysis on free recall performance, with group and trial (1, 2 and 3) as fixed effects, and participant as a random effect. As there was a ceiling effect for the three total recall trials, the assumption of normality was violated. We therefore carried out a generalized logistic mixed model on this variable, with group and trial as fixed effects, and participant as a random effect. Data were dummy-coded according to whether the entire list of words was correctly recalled (=1) or not (=0). Pairwise comparisons were conducted using t tests adjusted for multiple comparisons using the Holm–Bonferroni method. Mixed models were conducted using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in the R environment (R Core Team, 2020).

Finally, the relationships between background variables and verbal memory measures were examined with Spearman correlation coefficients, according to normality violation. Correction for multiple comparisons was done using the false discovery rate implemented in the ppcor package (Kim, 2015).

The significance level was set at 0.05.

2.4. Data availability

Anonymized demographics, alcohol use (AUDIT-CR items, binge drinking score), digit span, letter–number sequencing, and modified FCSRT, as well as the R code, are available at https://osf.io/d95tf/ (upon successful peer review).

3. Results

Analysis of the participants' demographic characteristics (see Table 1) revealed no significant differences between the BD and SD groups on either sex ratio, age, or education level. However, significant differences were found on each alcohol use measure. As expected, BD participants scored more highly than SD participants on the AUDIT-CR items, binge drinking, consumption speed, episodes of intoxication over the previous 6 months, ratio of intoxication episodes to total number of drinking occasions, and weekly alcohol consumption (all ps < 0.001). Information on other substances use revealed no significant differences on cigarette smoking and nicotine dependence. Depression and both state and trait anxiety symptoms were more severe in the BD group than in the SD group, but mean differences were nonsignificant (all ps > 0.18).

Table 1
Demographics, alcohol and other substance use and mood assessment of college students stratified as binge drinkers or social drinkers.

	Binge drinkers (n = 23)	Social drinkers (n = 23)	P value
Demographics			
Sex (% men)	39.13	43.48	0.76
Age	20.74 ± 1.51 (18–24)	20.83 ± 1.56 (18–25)	0.84
Education level	13.39 ± 1.64 (11–17)	13.13 ± 1.36 (11–17)	0.61
Alcohol and other substance use			
AUDIT CR total score	9.17 ± 1.58 (7–12)	3.35 ± 1.67 (1–6)	**<0.001**
Binge drinking score	39.17 ± 12.64 (24–74)	9.83 ± 5.32 (2–20)	**<0.001**
Consumption speed (drinks/hour)	2.83 ± 0.78 (2–5)	1.52 ± 0.71 (0.5–3)	**<0.001**
Episodes of intoxication in previous 6 months	16.65 ± 10.77 (6–50)	1.22 ± 1.44 (0–4)	**<0.001**
Percentage of times drinking to intoxication	56.52 ± 19.68 (10–90)	12.61 ± 12.87 (0–50)	**<0.001**
Alcohol units per week	17.35 ± 14.91 (3–63)	5.14 ± 4.66 (1–20)	**<0.001**
Current cigarette smokers (%)	39.13	26.09	0.34
FTND score	0.78 ± 1.67 (0–6)	0.48 ± 1.12 (0–5)	0.85
Current cannabis users (%)	43.48	26.09	0.22
Cannabis Abuse Screening Test	1.91 ± 3.26 (0–12)	0.87 ± 2.72 (0–13)	0.14
Depression and anxiety symptoms			
BDI	5.52 ± 5.43 (0–19)	4.13 ± 4.75 (0–18)	0.18
STAI-Trait	44.53 ± 12.07 (24–70)	39.91 ± 11.61 (20–49)	0.19
STAI-State	35.83 ± 12.57 (20–74)	32.26 ± 8.65 (23–61)	0.40

Note. Data are shown as mean ± SD (min–max) unless otherwise specified. AUDIT = Alcohol Use Disorders Identification Test; FTND = Fagerström Test for Nicotine Dependence; STAI = State–Trait Anxiety Inventory; Significant p-values are indicated in bold characters.

3.1. Group comparisons on memory measures

Performances of groups on the working memory task and the FCSRT are displayed in Table 2. Results revealed no significant differences concerning working memory measures. By contrast, there were significant differences for several FCSRT measures.

First, results showed a marginally lower immediate cued recall score and higher number of intrusions for the BD group. The free recall and total recall scores were significantly lower for the BD group than for the SD group. The BD group also exhibited a higher number of perseverations than the SD group during the free recall trials. Finally, the recognition phase did not reveal any significant difference between the two groups.

The linear mixed model analysis conducted on free recall performances, with group and trial (1, 2 and 3) as fixed effects and participant as a random effect, revealed significant main effects of group, $F(1, 46) = 10.00$, $p = 0.002$, and trial, $F(2, 92) = 112.44$, $p < 0.001$, and a nonsignificant Group × Trial interaction, $F(2,92) = 0.64$, $p = 0.529$. Post hoc comparisons with Holm–Bonferroni correction and Satterthwaite's approximation for degrees of freedom revealed that the means for the three trials differed significantly between the two groups. (Trial 1: $p = 0.0499$, Cohen's $d = 0.53$; Trial 2: $p = 0.001$, Cohen's $d = 0.87$; and Trial 3: $p < 0.003$, Cohen's $d = 0.88$).

The generalized mixed model conducted on total recall performances revealed significant main effects of trial, $\chi^2(2) = 16.66$; $p < 0.001$; $R^2 = 0.21$, and group, $\chi^2(1) = 8.93$; $p = 0.003$; $R^2 = 0.15$, while the Group × Trial interaction was not significant, $\chi^2(2) = 4.35$; $p = 0.11$; $R^2 = 0.63$. Post hoc comparisons revealed that performances on the first trial differed marginally between the two groups ($p = 0.09$), whereas performances on the second and third trials were similar ($p = 0.99$ and $p = 1$).

Fig. 1 displays means and standard errors for the BD and SD groups, as well as participants' scatterplots, for the free and total recall trials of the modified FCSRT.

Table 2
Verbal memory performance between binge drinkers and social drinkers.

	Binge drinkers (n = 23)	Social drinkers (n = 23)	P value
Working memory			
Forward digit span	6.65 ± 1.11 (4–9)	6.61 ± 1.16 (5–10)	0.71
Backward digit span	5.48 ± 1.31 (3–8)	5.83 ± 1.61 (4–10)	0.54
Letter-number sequencing	11.96 ± 2.74 (6–17)	12.39 ± 2.97 (7–19)	0.61
Modified free and cued selective reminding test			
Immediate free recall	22.96 ± 1.92 (16–24)	23.74 ± 0.51 (22–24)	0.08
Sum of free recalls	50.04 ± 6.70 (37–61)	55.48 ± 5.11 (45–65)	**0.009**
Sum of total recalls	70.65 ± 1.61 (67–72)	71.74 ± 0.54 (70–72)	**0.007**
Number of intrusions	0.74 ± 1.14 (0–3)	0.30 ± 1.06 (5–30)	0.08
Number of perseverations	5.52 ± 4.59 (0–16)	1.74 ± 2.83 (0–13)	**0.001**
Correct recognitions	23.96 ± 0.21 (23–24)	23.91 ± 0.42 (22–24)	0.99
False recognitions	0.09 ± 0.29 (0–1)	0.09 ± 0.29 (0–1)	0.99
False recognitions	0.00 ± 0.00 (0–0)	0.00 ± 0.00	–

Note. Data are shown as mean ± SD (min–max). Significant p-values are indicated in bold characters.

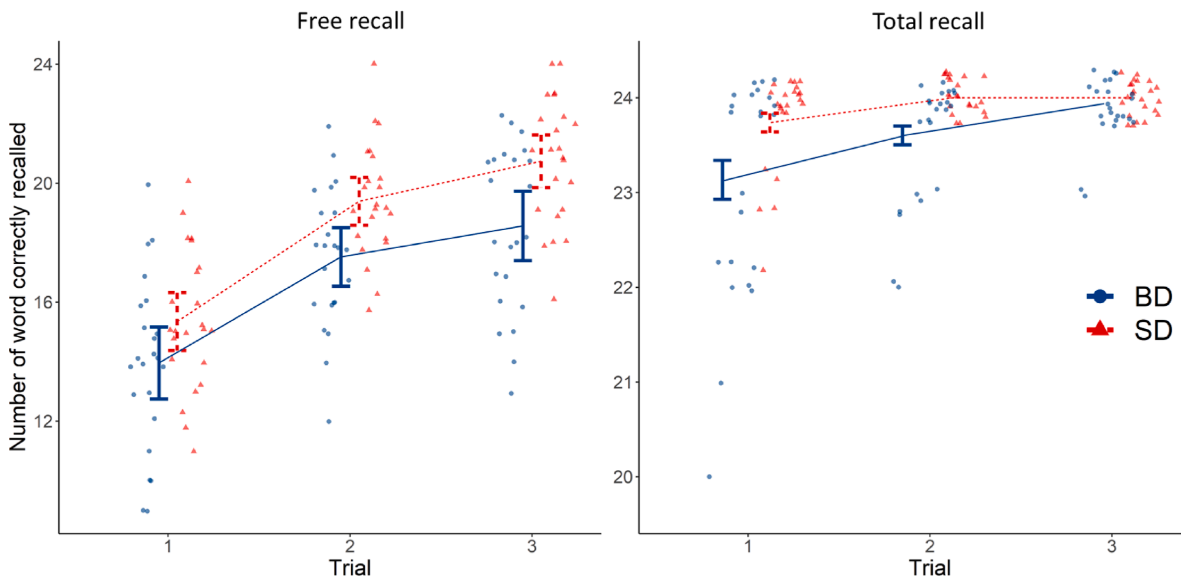

Fig. 1. Comparison between Binge Drinkers (BD) and Social Drinkers (SD) on recalls of the three trials of the modified free and cued recall selective reminding test. Figure displays mean ± standard error and participants' scatterplots with jitter.

3.2. Correlational analyses

Relationships between the variables were investigated using correlational analyses on the whole sample of participants, to further explore the associations between cognitive measures of memory functioning and clinical variables (Table 3). Because age and education level might interfere with results, they were controlled using partial correlations. Results revealed that the free recall score, a measure of recollection abilities, was negatively and significantly correlated with the binge drinking score and the frequency of intoxication episodes in the previous 6 months. The total recall score, a measure of storage efficiency, was negatively and significantly correlated with several alcohol consumption variables, including the AUDIT-CR items, the binge drinking score, consumption speed, frequency of intoxication episodes, and mean weekly number of alcohol units. The number of perseverations was positively and significantly correlated with the AUDIT-CR items, the binge drinking score, the frequency of intoxication episodes in the previous 6 months, and the ratio of intoxication episodes to drinking occasions. There were no significant correlations for the immediate cued recall score.

Table 3
Partial correlations, corrected for age and education level, between verbal episodic memory scores and alcohol, cannabis, depression and anxiety measures and in the whole sample.

	Immediate free recall	Sum of free recalls	Sum of total recalls	Perseverations
AUDIT CR	−0.20	−0.33	−0.40*	0.46*
Binge drinking score	−0.16	−0.39*	−0.42*	0.48*
Consumption speed	−0.08	−0.28	−0.42*	0.27
Episodes of intoxication in previous 6 months	−0.24	−0.43*	−0.46*	0.49*
Percentage of times drinking to intoxication	−0.07	−0.30	−0.24	0.50*
Alcohol units per week	−0.11	−0.27	−0.38*	0.27
FTND score	0.02	0.13	−0.19	−0.23
Cannabis Abuse Screening Test	−0.11	0.03	−0.08	−0.08
Beck Depression Inventory	0.04	0.00	−0.03	0.15
STAI-Trait	0.17	0.05	−0.06	0.10
STAI-State	0.14	−0.10	0.16	−0.06

Note. AUDIT = Alcohol Use Disorders Identification Test; FTND = Fagerström Test for Nicotine Dependence; STAI = State–Trait Anxiety Inventory.
* < 0.05 with FDR correction.

4. Discussion

The aim of the present study was to investigate verbal memory impairment associated with binge drinking behavior, in order to identify memory processes that might be specifically affected by this pattern of consumption. Results revealed a differential impact, as verbal working memory was found to be unaffected, whereas verbal episodic memory was affected, owing to less proficient storage and retrieval processes.

More specifically, results of the working memory tasks revealed no significant differences between groups. In line with Baddeley (2000)'s working memory model, results of the forward digit span task suggested preservation of the phonological loop among BDs. Likewise, although the backward digit span task and the Letter–Number Sequencing test increasingly elicited the central executive component of working memory, this did not seem to be affected in our young BDs. This first result contrasts with some previous studies, which highlighted reduced working memory proficiency in BDs (Carbia et al., 2017; Parada et al., 2012; Sanhueza et al., 2011; Squeglia et al., 2011; Townshend & Duka, 2005). However, it is congruent with a study that found no significant relationship between binge drinking scores and performances on the Letter–Number Sequencing test in a sample of 121 students (Bø, Billieux, Gjerde, Eilertsen, & Landrø, 2017). One possible explanation therefore lies in the test modality of the test, as most of the studies that observed a working memory deficit found it in the visuospatial modality, not the auditory–verbal one (see Carbia et al., 2018). Another possible explanation lies in the fragile relationship between the executive component of working memory and the tests that we selected for the present study. In particular, although the Letter–Number Sequencing test is widely used in clinical settings to assess mental load, it has been found to be poorly related to more complex working memory processes (Crowe, 2000; Egeland, 2015).

Concerning episodic memory, in line with data in the literature (Carbia et al., 2017; Mota et al., 2013; Parada et al., 2011; Winward et al., 2014), which do relate to the same modality (i.e., verbal items), the results of the modified FCSRT highlighted weaker recall in the BD group than in the SD group. More specifically, our results support the hypothesis that the storage and retrieval processes of episodic memory are affected by binge drinking behavior. These results could not be attributed to differences between groups on anxiety or depressive symptoms, or the use of other substances, as these were similar across groups.

The free recall score was noticeably lower among BDs, suggesting difficulty with the process of retrieving verbal information from episodic memory. Although the results of the mixed linear model analysis did not reveal a significant group × trial interaction, post hoc analyses and learning curves from the three trials suggested that the performance gap between BDs and SDs gradually widened. We therefore encourage future studies to investigate BDs' learning curves across a larger number of recall trials. In addition, correlation analyses highlighted significant relationships between the free recall score and the binge drinking score and frequency of intoxication episodes over the previous 6 months. These results are in line with a previous report of a relationship between impaired free recall of verbal material and binge drinking (Carbia et al., 2018).

The total recall scores are more complex to interpret, owing to the ceiling effect we observed. Although we increased the difficulty of the original task by adding eight target items (+50%) to the original task, results showed that the task remained too easy, as some participants in both groups quickly achieved maximum delayed recall. Even so, the total recall score unequivocally revealed a lower level of performance for BDs, which was corroborated by the analyses conducted with a mixed generalized model, highlighting a main effect of group. Furthermore, correlation analyses supported the idea that several alcohol-related variables were negatively associated with total recall, especially the binge drinking score and some of its components, such as the speed of alcohol consumption, which is a hallmark of binge drinking, and the frequency of intoxication episodes over the previous 6 months. Taken together, these results suggest that the storage of verbal information in episodic memory is impaired in binge drinking. However, some could argue that our interpretation is not consistent with the fact that recognition, which also reflects storage efficiency, was similar across groups. Although we agree with this objection, it is important to bear in mind that the recognition phase was too easy for our participants, such that the means for the two groups were extremely close to the maximum score.

Accordingly, the assumption that storage is affected by binge drinking appears consistent with the literature. This process has been linked to the hippocampal formation (Eichenbaum, 2017), and alcohol consumption has been shown to alter this brain area in studies of AUDs and their most severe neurological complication, Korsakoff's syndrome (see, for example, Le Berre et al., 2014). Moreover, on a clinical level, binge drinking has been associated with blackouts (Hingson, Zha, Simons-Morton, & White, 2016), which are manifestations of damage to the hippocampal system (Hermens & Lagopoulos, 2018). Finally, in a preclinical study, alterations in the basic cellular mechanisms of learning (i.e., long-term depression) were found in the hippocampus of adolescent rats after only two binge drinking episodes (Silvestre de Ferron et al., 2015).

Finally, we counted a large number of perseverations during recall among BDs. This result, in line with previous data (Sanhueza et al., 2011), suggests that BDs had difficulty monitoring the task. They seemed to have problems knowing precisely what information had or had not already been given. Impairment of monitoring processes in BDs has already been highlighted in electrophysiological and behavioral studies of executive function (Lannoy et al., 2017a, 2017b, 2018), linking memory difficulties, at least in part, to executive processes.

The results of the present study have major implications, as they point to the existence of a core verbal memory deficit in young adult students who engage in binge drinking. Therefore, the well documented negative impact of binge drinking on the academic performance (Kuntsche et al., 2017; Patte et al., 2017) of this population could partly stem from this memory deficit. In addition, it may hamper the integration of the negative consequences of binge drinking episodes and constitute a risk factor for the subsequent development of an AUD. Longitudinal studies are obviously needed to confirm this hypothesis.

4.1. Limitations

The present study had several limitations that need to be acknowledged. The first one is related to the ceiling effect found in the total recall and recognition phases of the modified FCSRT, even though the number of items had been increased. Further studies could be implemented and modulate the number of words and or the encoding conditions in order to make the task more difficult and thus avoid these ceiling effects. Second, like most studies on this topic, measures of substance use were based on retrospective statements, and although the questionnaires used have been validated, it is likely that they were not the perfect reflection of real consumptions, especially as we highlighted an impairment in episodic memory for among BDs. Nevertheless, it is unlikely that this potential distortion would have affected group membership and therefore the main results of the present study. The correlation analyses, however, were probably more sensitive to this effect. To prevent from this confounding, further studies could be based on a longitudinal design with an agenda of alcohol consumption or use an ecological momentary assessment (Kuntsche & Labhart, 2013). Third, in line with numerous previous studies, we found that college BDs were more likely to use other substances (O'Grady, Arria, Fitzelle, & Wish, 2008). Accordingly, we descriptively found a higher prevalence of cannabis use and therefore a potential cumulated effect of this substance on verbal memory remains likely. Finally, several other variables could differ between groups and contribute to the observed differences, such as family history of alcoholism, lifetime alcohol use, genetic (see for instance: (Richter-Schmidinger et al., 2011), or even overall cognitive functioning. Therefore further studies will be necessary to confirm and deepen our results.

5. Conclusion

Results of the present study showed that binge drinking negatively impacts verbal episodic memory processes (i.e., storage and recollection), as well as the monitoring of verbal learning tasks. Going beyond the categorical conception of binge drinking, we found that the levels of efficiency of these memory processes were systematically associated with the number of intoxication episodes over the previous 6 months, highlighting the particularly harmful nature of repeated alcohol intoxication for memory processes. The findings from this study could be used to develop information campaigns among students and possibly also rehabilitation interventions among those who engage in binge drinking.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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