Original Paper

Craving is everything: An eye-tracking exploration of attentional bias in binge drinking

Journal of Psychopharmacology
1–12

DOI: 10.1177/0269881120913131
journals.sagepub.com/home/jop

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Abstract

Background: Attentional bias towards alcohol-related stimuli is a core characteristic of severe alcohol use disorders (AUD), directly linked to clinical variables (e.g. alcohol consumption, relapse). Nevertheless, the extent of this bias in subclinical populations remains poorly documented. This is particularly true for binge drinking, an alcohol consumption pattern highly prevalent in youth, characterised by an alternation between excessive intakes and withdrawal periods.

Aims: We used eye-tracking to: (a) measure attentional bias in binge drinking, (b) determine its time course by dissociating early/late processing stages, (c) clarify its specificity for alcohol-related stimuli compared to other appetitive stimulations and (d) explore its modulation by current craving intensity.

Methods: Binge drinkers (n=42) and matched controls (n=43) performed a visual probe task, requiring visual targets preceded by pairs of pictures to be processed, with three conditions (i.e. alcohol vs. soft drink, alcohol vs. high-calorie food, high-calorie food vs. low-calorie food).

Results: No group difference was observed for early processing (i.e. first area of interest visited). Dwell times highlighted a bias towards soft drinks and healthy food among controls, without any global bias towards alcohol in binge drinkers. Centrally, a comparison of binge drinkers with low versus high current craving intensity indicated that binge drinking was associated with a bias towards alcohol and high-calorie food only in the presence of a high craving towards these stimuli.

Conclusion: Attentional bias towards alcohol reported in severe AUD is only found in binge drinkers in the presence of high craving and is generalised to other appetitive cues.

Keywords

Alcohol, attentional bias, eye tracking, alcohol use disorders, binge drinking

Introduction

Binge drinking, constituting a frequent excessive alcohol consumption pattern in adolescents and young adults (Archie et al., 2012), is now considered as a specific drinking habit. Its distinctive characteristics are the presence of excessive but episodic consumption, leading to a repeated alternation between intense intoxications and withdrawal periods, associated with a strong motivation to reach drunkenness rapidly (Rolland and Naassila, 2017). The multiple withdrawal periods related to binge drinking appear harmful at both cognitive and cerebral levels when compared to more regular consumption patterns without extreme alcohol intoxications (López-Caneda et al., 2013). Indeed, binge drinking has recently been the focus of a large range of psychological and neuroscience explorations (e.g. Scaife and Duka, 2009; Lannoy et al., 2019), consistently showing its consequences on cognitive abilities such as memory and executive functions (for reviews, see Carbia et al., 2018 and Hermens et al., 2013). As a whole, binge drinking is thus a specific alcohol consumption pattern related to well-established neuropsychological and cerebral negative effects.

Although attentional biases towards alcohol-related stimuli emerged during the two last decades as a key process in alcohol use disorders (AUD), none of the numerous studies that focused on neurocognitive abilities in binge drinking has assessed the presence and extent of these biases in a clearly defined sample of binge drinkers. Attentional biases are globally defined as the tendency to allocate one's attentional resources preferentially to alcohol cues when such cues are presented together with other stimuli (usually neutral or soft-drink cues). They are supposed to play a major role in the emergence and persistence of AUD by

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attracting attention towards alcohol-related stimuli and thus leading to an increase in the incentive motivational properties of such stimuli. This subsequently leads to an increase in alcohol consumption, craving (i.e. the intense urge and desire to drink alcohol, constituting a primary subjective motivational state promoting compulsive consumption; Flaudias et al., 2019; Skinner and Aubin, 2010) and relapse risk (Cox et al., 2014; Field and Eastwood, 2005; Manchery et al., 2017; but see also Field et al., 2014). Many behavioral studies have demonstrated the presence of attention biases towards alcohol-related stimuli in severe AUD (for a review, see Field and Cox, 2008). Moreover, several studies have revealed a direct link between the strength of the attentional bias and the severity of alcohol-related problems (Jones et al., 2006) or the relapse risk over a six-month follow-up period (Garland et al., 2012). Despite some currently ongoing debates (Boffo et al., 2019; Cristea et al., 2016; Wiers et al., 2018), this pivotal role of attentional bias in severe AUD has been reinforced by recent investigations (Heitmann et al., 2018; Rinck et al., 2018) showing that training paradigms able to reduce this attentional bias efficiently diminished alcohol consumption and relapse risk, suggesting a causal link between attentional biases and alcohol-related problems.

The presence of attentional bias goes beyond severe AUD, as it may also concern subclinical consumption patterns (e.g. heavy drinking, regular drinking or hazardous drinking). Several experimental investigations have shown attentional bias in populations presenting subclinical chronic consumption habits (e.g. Cox et al., 2015; Fadardi and Cox, 2009; Field and Eastwood, 2005; Weafer and Fillmore, 2013). However, while findings obtained in severe AUD appear stable, inconsistent results have been found in subclinical populations (Ceballos et al., 2009; Field et al., 2005, 2011; Sharma et al., 2001), which could partly be explained by the serious lack of coherence regarding the terminology, inclusion criteria and thresholds chosen in these studies to categorise alcohol consumption patterns. The population explored is indeed often poorly specified: participants are mostly recruited among college students, assuming a high level of alcohol consumption in this population, and the control of potentially biasing variables (e.g. presence of co-morbid depressive/anxious states or other addictive disorders, variations in alcohol consumption frequency/intensity) is usually limited. To address this issue and to clarify the presence of attentional bias towards alcohol in subclinical populations, the present paper will focus on binge drinking, as it is a very frequent consumption pattern in youth and constitutes a clearly defined and specific consumption pattern in which attentional biases have not yet been explored. The definition criteria for binge drinking have long been a matter of debate, but a consensus has progressively emerged to promote the computation of a binge-drinking score evaluating the key characteristics of this habit (Crego et al., 2009; Townshend and Duka, 2002). This binge-drinking score, focusing on consumption speed, drunkenness frequency, and drunkenness ratio, has been largely used in recent papers (e.g. Bø et al., 2017; Gierski et al., 2017; Laghi et al., 2016; Smith et al., 2017), and we will also capitalise on this score to offer an optimal characterisation of binge drinkers.

The visual probe task (VPT; see Methods for a full description) is the most common task to study attentional bias. Nevertheless, inferring the presence of attentional bias exclusively through the classical VPT behavioural measures (i.e. reaction times (RT) and performance) is questionable, which could partly explain the very low internal reliability of the task (Ataya et al., 2012). Indeed, such measures only provide insights about the final output of all the successive stages involved in processing alcohol cues (Field and Cox, 2008), without dissociating early (i.e. initial orientation of attentional resources) and late (i.e. modulation of attentional allocation between stimuli) processing stages. Cognitive control is thought to increase with the successive stimulus processing stages, and it is thus essential to distinguish early and late stages to measure the attentional biases induced by alcohol stimuli appropriately and to specify its core processes.

A reliable way to assess attentional bias is to go beyond such classical measures by using eye-tracking. This tool provides insights regarding the time course of the bias by measuring eye movements and gaze position throughout the entire task, with high temporal resolution (Popa et al., 2015). Eye-tracking directly and precisely measures the consecutive steps involved in attentional processing, thus offering a deeper understanding of the underlying processes (Armstrong and Olatunji, 2012). In particular, eye-tracking indices allow early processes to be separated from later ones. On the one hand, the first area of interest (AOI) visited informs about attentional bias in the first stages of stimulus processing, reflecting an initial attentional capture that occurs quickly and early during a trial. On the other hand, the dwell time (i.e. overall fixation time on each stimulus) reflects processes that are progressively deployed over time and that are related to the controlled maintenance of attention on alcohol-related stimuli (McAteer et al., 2015, 2018; Monem and Fillmore, 2017). Therefore, the eye-tracking method clarifies the spatial and temporal dynamics of the reported bias, from the initial orienting to the more controlled attentional processing stages, and thereby improves the reliability of the traditional paradigms (Christiansen et al., 2015; Miller and Fillmore, 2010). Results from studies using this technique among subclinical populations with excessive alcohol use (i.e. heavy, hazardous or regular drinkers) clearly showed that indices based on eye movements provide a more robust attentional bias assessment than RT (e.g. Christiansen et al., 2015; Field et al., 2011). While these results mainly indicated the presence of attentional bias towards alcohol-related stimuli in heavy drinkers at the later and more controlled stages of information processing (McAteer et al., 2015, 2018; Miller and Fillmore, 2010; Monem and Fillmore, 2017), the time course of the bias remains to be more deeply understood through the comparison between different eye-tracking indices.

Another uncertainty regarding attentional bias in AUD is its specificity towards alcohol-related stimuli. Previous studies have mostly investigated the presence of attentional bias towards alcohol by presenting alcohol-related stimuli together with non-alcoholic non-appetitive or emotionally neutral stimuli. However, it is not clear whether the bias is specifically caused by the alcohol-related nature of the cues or at least partly by their highly appetitive nature. Recent research exploring inhibitory control failure (presumably caused by attentional bias) in young drinkers compared alcohol-related stimuli with non-alcoholic appetitive stimuli and non-alcoholic non-appetitive stimuli. A significant effect of both appetitive cues was shown, beyond their alcohol-related nature (Monk et al., 2017; Qureshi et al., 2019). The appetitive value of the stimuli should thus be further explored through attentional bias paradigms, as a generalised bias towards all

appetitive cues without any preference for the alcohol-related ones would imply a strong revision of the assumptions concerning attentional bias in AUD.

Finally, the role played by craving in the presence and intensity of this bias is still unclear. The incentive-sensitisation theory (Robinson and Berridge, 1993) describes attentional bias as the result of repetitive alcohol exposures, leading to a more sensitised dopaminergic system that subsequently enhances the incentive-motivational properties of alcohol cues. Becoming more salient, these cues grab the consumer's attention. According to this theory, the sensitisation of the dopaminergic system also results in the emergence of a subjective craving towards the substance (i.e. an appetitive experienced motivational state) that is strongly related to attentional bias. Similar predictions of a reciprocal excitatory relationship between the two processes can also be found in the extensions of this model (Franken, 2003; Ryan, 2002) and have been widely confirmed by the literature. Although most studies exploring alcohol-related attentional bias in subclinical populations did not assess participants' craving, a meta-analysis of 68 data sets demonstrated a significant association between the magnitude of attentional bias and the strength of subjective craving (Field et al., 2009). One eye-tracking study (Hobson et al., 2013) has even suggested that craving intensity is a stronger determinant of attentional bias than the level of alcohol consumption in regular drinkers. Nevertheless, these associations have not been supported by more recent studies (Van Duijvenbode et al., 2017; Wilcockson et al., 2019) and thus need further investigation.

In view of the above-mentioned limits related to previous studies, the four main objectives of the present study were as follows. First, this study aimed to explore, for the first time, the presence of attentional bias in a specific population of subclinical alcohol consumers, namely binge drinkers, using eye-tracking measures. We hypothesised that binge drinkers, when compared to controls, would show an attentional bias towards alcohol-related stimuli. Second, the study aimed to investigate the time course of the potential bias by combining the VPT with eye-tracking measures. This integration allowed us to explore the successive steps involved in attentional processing and to dissociate early and late components of attentional bias. We hypothesised that the bias would mostly occur during the later and more controlled stages of attentional processing (indexed by dwell times) in binge drinking, in line with previous results in other subclinical populations (McAteer et al., 2015; 2018; Miller and Fillmore, 2010). Third, the study sought to determine whether the bias was exclusively related to alcohol or could be generalised to other appetitive stimuli. To do this, a comparison between alcohol-related stimuli, neutral ones (i.e. pictures of soft drink or healthy food) and other appetitive ones (i.e. pictures of high-calorie food) was performed. We hypothesised that an attentional bias would be present for other appetitive stimuli when compared to neutral ones, and thus that attentional bias is not specifically related to alcohol in subclinical AUD. The presence of such a generalised bias towards appetitive stimuli would question the experimental and clinical interest of the so-called alcohol-related bias. Fourth, the study explored the role played by subjective craving for alcohol or food on the magnitude of the bias towards alcohol-related or food-related stimuli, as we hypothesised that the eye-tracking correlates of attentional bias, and particularly those related to late processing stages (i.e. dwell time), would be strongly modulated by the current craving intensity towards appetitive cues.

Methods

Participants

Participants were recruited via an online screening questionnaire sent through social networks to students from UCLouvain (Belgium). The survey assessed sociodemographic (i.e. age, sex, mother tongue) and nutritional (i.e. diet, consumption frequency per food types) variables. A thorough evaluation of alcohol consumption characteristics during the last six months was also conducted, encompassing: the evaluation of the mean number of alcohol units per week and per occasion (an occasion being defined as an event lasting several hours, e.g. dinner with friends, evening party); the mean number of drinking and binge drinking occasions (defined as the consumption of more than six units of alcohol) per week; the consumption speed (in units per hour); the drunkenness frequency (i.e. number of drunkenness episodes: 'How many times have you been drunk during the last six months', drunkenness being defined as including the loss of motor/verbal coordination, the loss of self-control and/or nausea); the drunkenness ratio (i.e. percentage of drunkenness episodes compared to all drinking episodes); and the age when alcohol was first consumed. Participants were informed about the number of alcohol units per type of alcoholic beverages (an alcohol unit corresponding to 10 g of pure ethanol in Belgium) and were asked to fill in a questionnaire assessing alcohol-related disorders (Alcohol Use Disorder Identification Test (AUDIT); French validation: Gache et al., 2005). Exclusion criteria for both groups were the presence of: a parental history of severe AUD; a personal past or current severe AUD (as diagnosed through DSM-5 criteria); daily alcohol consumption; a personal past or present psychological, addictive (except nicotine and occasional cannabis use) psychiatric or neurological disorder (including clinical depressive or anxious state); uncorrected visual deficits; low French speaking abilities; vegetarian or vegan diets.

Two groups of participants (binge drinkers, controls) were constituted (see Table 1) based on alcohol consumption characteristics, including binge-drinking score (Townshend and Duka, 2005) and AUDIT score (Gache et al., 2005). The binge-drinking score was computed using the following formula: (4×consumption speed) + drunkenness frequency + (0.2×drunkenness percentage). Following the online screening, 85 participants (75 right-handed) were selected to take part in the experiment: 42 binge drinkers (BD; binge-drinking score $\geqslant$22; AUDIT score $\geqslant$9) and 43 control participants (CTL; binge-drinking score $\leqslant$12; AUDIT score $\leqslant$9). A power computation (performed in R v3.6.1; R Foundation for Statistical Computing, Vienna, Austria) indicated that a sample size of 53 was required to detect a conventional medium effect size (Cohen, 1992) with 0.80 power, as fulfilled by our sample size. To control for the influence of psychopathological co-morbidities, participants filled in questionnaires using Qualtrics software (Qualtrics, LLC, Provo, UT), assessing depressive symptoms (Beck Depression Inventory (BDI-13); French validation: Beck et al., 1998), anxiety (State–Trait Anxiety Inventory (STAI); French validation: Bruchon-Schweitzer and Paulhan, 1993) and impulsivity (UPPS-P Impulsive Behavior Scale; French validation: Billieux et al., 2012).

All participants were asked to refrain from consuming alcohol during the days preceding the experimental session and were questioned about their recent consumption before starting the experiment.

Procedure

Participants provided written informed consent to take part in the study and were not aware of the hypotheses being tested. Just before the task, online questionnaires evaluated current (i.e. right now) craving using Qualtrics software. Visual analogue scales (VAS; 0–100) assessed the craving intensity related to alcohol and salty and sugary food. A complementary craving measure was performed using the Alcohol Craving Questionnaire Short Form Revised (for alcohol craving) and adapted forms for salty and sugary food. We only report (see median split analyses below) the results related to the craving median split performed on the VAS, as the correlations between the two craving measures were high (i.e. alcohol craving: r=0.634, p<0.001; salty food craving: r=0.675, p<0.001; sugary food craving: r=0.692, p<0.001) and as similar results were obtained when performing the median split on craving questionnaires (see Supplemental Material). Then, participants were seated in front of a blank screen and tested individually in a quiet room. They received verbal instructions to perform the task, without being aware of its rationale. The experimental task was a computerised behavioural task composed of three blocks and lasted 45 minutes. A nine-point calibration of each participant's eye-gaze position was set up at the beginning of each block through a display screen. After the task, participants were asked to fill in the online questionnaires assessing psychological co-morbidities. The study protocol was performed in accordance with the ethical standards established by the Declaration of Helsinki and was approved by the Ethics Committee of the Psychological Sciences Research Institute (UCLouvain). At the end of the experiment, participants were debriefed and received a compensation of €10 for completing the experiment.

Apparatus

Participants were seated on an adjustable desk chair, facing an eye-tracker camera placed 60 cm away from a Dell PC equipped with a 21.5-inch LCD screen (resolution 1080×1920; refresh rate 60 Hz). Their head movements were reduced using a forehead and chin stabiliser. The presentation of the experimental task and its synchronisation with eye-tracking were controlled using OpenSesame software (Mathôt et al., 2012). Eye movements were recorded using an Eye-link 1000 tower-mounted eye-tracker (SR Research Ltd, Mississauga, Canada; sampling rate 1000 Hz; average accuracy range 0.25°–0.5°, gaze tracking range 32° horizontally and 25° vertically).

VPT

At the beginning of each trial, a central fixation dot appeared on the black background screen, and participants were asked to fixate their gaze on it. This instruction ensured that participants initially focused their visual attention at the centre of the screen in each trial. The fixation dot was also used as a drift check to confirm the reliability of the eye-gaze calibration. Once the participant's eyes were detected at the centre of the screen by the eye-tracking device, the fixation dot was removed and was directly followed by the presentation of two pictures. They were displayed randomly on the left and right side of the computer screen for a 2000 ms period and then replaced by a probe (i.e. a white arrow on a black background, pointing up or down) appearing at the location previously occupied by one of the pictures. Participants were instructed to respond to the orientation of the probe by pressing the 'up' or 'down' key on a keyboard as quickly and accurately as possible. Each trial was separated by an inter-trial interval of random duration (between 500 and 1500 ms). Faster responses to probes replacing the alcohol-related stimulus (compared to the neutral one) are interpreted as an attentional bias towards alcohol-related stimuli.

Participants completed three versions of the VPT: one presenting alcohol and soft-drink stimuli (i.e. drink block; see Figure 1), one presenting alcohol and food stimuli (i.e. drink–food block) and one presenting salty or sugary food and healthy food (i.e. food block). The three blocks were administrated in the following order: the drink block was presented first to obtain the standard measure of the alcohol-related attentional bias, followed by the drink–food block or the food block in a counterbalanced order. Visual probes replaced the two types of pictures with equal frequency. Each block contained 84 trials in total, including four practice trials (i.e. the same task performed on stimuli not included in the experimental phase) that participants completed first.

Stimuli

Three pictures sets were used for the VPT. For the drink block, 20 pairs of coloured pictures of alcoholic beverages (e.g. bottle of vodka, can of beer) and matched pictures of non-alcoholic beverages (e.g. bottle of water, soft drink can) without context, extracted from the validated ABPS pictures battery (Pronk et al., 2015), were displayed on a white background. The brand and writings of the beverage were systematically blurred, and each picture pair was matched on perceptual features such as size (250×250 pixels; 6.05×6.05° visual angle), brightness and salience. For the drink–food block, we used a set of pictures depicting other alcoholic drinks from the ABPS battery and high-calorie food from the Food-Pics battery (e.g. bowl of ice cream, hamburger; Blechert et al., 2014). All pictures were matched on brightness and salience using the SHINE toolbox (Willenbockel et al., 2010). The same matching procedure was used for the food block, including a set of other pictures from the Food-Pics battery depicting high-calorie food, all matched with pictures of low-calorie food (e.g. fruit, vegetables) on basic perceptual features such as size (250×250 pixels; 6.05×6.05° visual angle), brightness and salience using the SHINE toolbox. Stimuli were presented in black and white in the drink–food and food blocks. This is because the large variation in colours across food stimuli made it impossible to match them on this parameter, and it was thus decided to present these stimuli in black and white to avoid any strong perceptive difference (known to influence eye-tracking measures strongly) between stimuli types.

Data reduction and statistical analyses

A data-reduction procedure was performed for RT. Trials with incorrect responses (3.65% of trials) were removed prior to analysis, as well as trials with RT <200 ms (0.03% of trials) or >2000

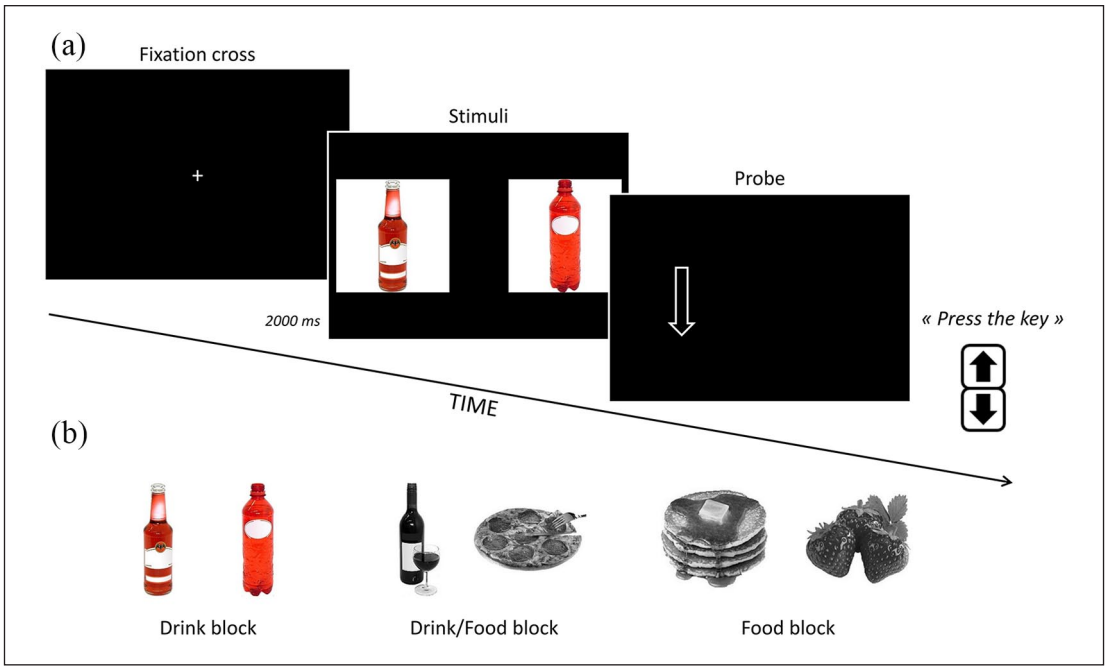

Figure 1. (a) Illustration of the alcohol-related visual probe task with alcohol-related versus non-alcohol-related (i.e. soft drink) stimuli. The task requires participants to respond as quickly as possible to the target probe by indicating on which side (left or right) the arrow appeared. The presence of an attentional bias towards alcohol is indexed by faster reaction times when the probe appears at the same location as the alcohol-related stimulus (as illustrated here) in comparison with a probe appearing at the same location as the soft drink. (b) Example of stimuli pairs for each block of the visual probe task (from left to right: drink block with alcohol/soft drink, drink–food block with alcohol/food and food block with sugary/healthy food).

ms (0.25% of trials). The spatial and temporal parameters of eye movements were extracted using Eyelink® Data Viewer (SR Research Ltd). Gaze samples were qualified as fixations or saccades according to the standard Eyelink algorithms. The dependent variables measured were the first AOI visited, which indicates the area that was first fixated at the beginning of each trial, and the dwell time, defined as the sum of fixation times on one of the areas during the whole trial. For the first AOI visited, the sum of the percentages for both stimuli is not equal to 100%, as the first fixation could be outside the two AOIs. Likewise, the sum of dwell times for both stimuli is not equal to 2000 ms, as the fixations could be outside the two AOIs.

All statistical analyses were performed using IBM SPSS Statistics for Windows v25.0 (IBM Corp., Armonk, NY). Between-group comparisons (i.e. independent *t*-tests) were performed on demographic and psychopathological characteristics, as well as on alcohol consumption variables. To estimate the internal reliability, we computed Cronbach's alpha for the following attentional bias measures: (a) RT, (b) first AOI visited and (c) gaze dwell time. Following a well-established procedure (Ataya et al., 2012; Christiansen et al., 2015; Van Ens et al., 2019), we calculated bias scores separately for each pair of pictures, leading to 20 bias scores for each attentional bias measure within each version of the VPT (drink, drink–food and food blocks). Separate repeated-measures analyses of variance (ANOVAs) were performed on RT for each block, with group (BD vs. CTL) as the between-subjects factor and type (alcohol vs. soft drink, alcohol vs. high-calorie food, salty or sugary food vs. healthy food) as the within-subjects factor. For each picture category, the type factor thus groups the trials in which the probe appeared at the same location as these pictures (e.g. all trials in which the arrow replaced the alcohol-related stimuli for 'alcohol' type). Eye-tracking measures were explored by using two 2×2 ANOVAs (first AOI visited and dwell time) performed for each version of the VPT, with group (BD vs. CTL) as the between-subjects factor and type (alcohol vs. soft drink, alcohol vs. high-calorie food, salty or sugary food vs. healthy food) as the within-subjects factor. For each ANOVA, comparisons within group and type were investigated, as well as interactions between the two factors. Regarding craving analyses, Pearson's two-tailed correlations with Bonferroni correction were first performed between attentional bias measures (i.e. RT, first AOI visited, dwell time for each stimulus type) and craving measures (i.e. VAS scores) to investigate the influence of craving levels on the magnitude of attentional bias towards alcohol and food-related stimuli in the whole sample. Multiple regressions for attentional bias were then conducted in each version of the VPT to explore the predictive power of craving (for alcohol, salty food, and sugary food), alcohol-related factors (AUDIT score and BD score) and psychopathological co-morbidities (depression, state/trait anxiety, and impulsivity) on attentional bias indexed by dwell times. Based on correlational results and in line with Hobson et al. (2013), median splits were then conducted on craving levels. Then, 2×2 ANOVAs were performed on RT, first AOI and dwell time separately for each group (BD and CTL) and each version of the VPT, with alcohol/salty food/sugary food craving

Table 1. Demographic, psychopathological and alcohol consumption measures (*M* (*SD*)) for binge drinkers (BD) and control (CTL) participants.

	BD (*N*=42)	CTL (*N*=43)
Demographic measures		
Sex ratio (male/female)^{ns}	20/22	20/23
Age^{ns}	21.36 (2.20)	21.07 (2.00)
Psychopathological measures		
Beck Depression Inventory^{ns}	4.61 (3.90)	4.29 (3.40)
State Anxiety Inventory^{ns}	33.79 (10.00)	36.14 (9.70)
Trait Anxiety Inventory^{ns}	42.36 (10.90)	42.47 (10.80)
UPPS-P*	46.05 (7.30)	42.16 (7.20)
Alcohol consumption measures		
*Alcohol Use Disorder Identification Test***	17.38 (5.00)	4.72 (3.10)
*Binge Drinking Score***	43.91 (23.19)	5.35 (3.89)
*Number of units per week***	22.74 (12.28)	3.15 (3.54)
*Number of occasions per week***	3.51 (1.36)	1.47 (1.24)
*Number of units per occasion***	5.71 (2.82)	2.20 (1.91)
*Number of binge drinking episodes per week***	1.47 (1.50)	0.13 (0.17)
*Consumption speed (units/hour)***	3.39 (1.07)	1.06 (0.74)
*Number of drunkenness episodes (last six months)***	27.68 (19.36)	0.91 (1.31)
*Drunkenness ratio (last six months)***	19.25 (28.92)	2.02 (6.17)
*Age at first alcohol consumption**	14.41 (0.95)	14.68 (2.61)
Craving measures (Visual Analogue Scale)		
*Alcohol craving***	28.48 (27.0)	8.58 (15.5)
*Salty food craving**	32.83 (25.6)	17.21 (21.8)
Sugary food craving^{ns}	33.76 (25.3)	26.14 (20.6)

*$p<0.05$; **$p<0.001$.
ns: not significant.

(high cravers vs. low cravers) as the between-subjects factor and type (alcohol vs. soft drink, alcohol vs. high-calorie food, salty or sugary food vs. healthy food) as the within-subjects factor. Finally, two complementary 2×2 ANOVAs (with group as the between-subjects factor and type as the within-subjects factor) were performed (see Supplemental Material for the results) on: (a) first fixation laterality for each version of the VPT to test for the presence of a potential pseudoneglect effect (Bowers and Heilman, 1980); and (b) dwell time for the first (T1: 0–1000 ms) and second (T2: 1000–2000 ms) stimuli presentation time periods in the drink block comparing alcohol and soft drinks in order to investigate the time course of the bias and to distinguish early and late processing stages.

Results

Demographic and psychopathological measures

As shown in Table 1, groups were well matched, as BD and CTL did not differ for age ($t(83)=0.620$, $p=0.537$), sex ratio ($\chi^2(1, N=85)=0.294$, $p=0.588$), depression ($t(83)=0.704$, $p=0.483$), trait anxiety ($t(83)=1.096$, $p=0.276$) or state anxiety ($t(83)=0.046$, $p=0.963$). By contrast, BD showed higher impulsivity ($t(83)=2.476$, $p=0.015$), alcohol craving ($t(83)=4.174$, $p<0.001$) and salty-food craving ($t(83)=3.031$, $p=0.003$). Finally, and as expected, BD participants had larger BD scores ($t(83)=10.751$, $p<0.001$) and AUDIT scores ($t(83)=13.978$, $p<0.001$).

Experimental measures

Internal reliability

Internal reliability is shown in Table 2. Cronbach's alpha was very low for classical measures (i.e. RT). Conversely, it was high for eye-tracking measures (i.e. first AOI visited and dwell time), being above the 0.70 cut-off conventionally considered as the minimum for acceptable internal reliability (Kline, 2000).

RT

RT are shown in Table 3. A main type effect was found in the drink–food block ($F(1, 83)=8.958$, $p=0.004$, $\eta^2=0.097$), showing shorter RT for food compared to alcohol. No significant main type effect was found in the drink and food blocks, and no significant main group effect or interaction was found in any block ($p>0.05$).

Eye-tracking measures

First AOI visited. Eye-tracking measures are shown in Table 4. A main type effect was found in the drink–food block ($F(1, 83)=60.566$, $p<0.001$, $\eta^2=0.422$), showing a higher frequency of first fixations on food compared to alcohol. No significant main type effect was found in the drink and food blocks, and no significant main group effect or interaction was found in any block ($p>0.05$).

Table 2. Internal reliability (Cronbach's alpha) of the drink, drink–food and food blocks of the VPT for RT and eye-tracking measures.

	RT	First AOI visited	Dwell time
Drink block	0.138	0.781	0.939
Drink–food block	0.082	0.924	0.911
Food block	0.013	0.970	0.923

Trials with RT outliers (i.e. <200 ms or >2000 ms) were excluded from the analyses.
VPT: visual probe task; RT: reaction time; AOI: area of interest.

Table 3. RT (*M* (*SD*) in ms) for drink, drink–food and food VPT for BD and CTL participants.

Variable	Condition	Type	BD (*N*=42)	CTL (*N*=43)
RT	Drink	Alcohol	582 (115)	574 (122)
		Soft drink	582 (115)	572 (121)
	Drink–food	Alcohol	586 (120)	573 (118)
		Food	577 (112)	564 (111)
	Food (salty)	Salty	572 (102)	571 (121)
		Healthy	570 (106)	566 (111)
	Food (sugary)	Sugary	572 (110)	570 (125)
		Healthy	579 (118)	568 (123)

Table 4. Eye-tracking indexes for drink, drink–food and food VPT (*M* (*SD*)) for BD and CTL participants.

Variable	Condition	Type	BD (*N*=42)	CTL (*N*=43)
First AOI visited (%)	Drink	Alcohol	47.29 (8.8)	45.61 (8.5)
		Soft drink	46.04 (8.7)	46.83 (9.4)
	Drink–food	Alcohol	42.89 (7.4)	42.09 (10.8)
		Food	54.64 (5.9)	51.19 (10.5)
	Food (salty)	Salty	49.88 (8.0)	47.73 (9.4)
		Healthy	47.74 (7.1)	47.56 (8.1)
	Food (sugary)	Sugary	49.29 (6.3)	47.09 (10.9)
		Healthy	48.81 (6.8)	47.67 (8.2)
Dwell time (ms)	Drink	Alcohol	578 (188)	526 (173)
		Soft drink	584 (153)	638 (252)
	Drink–food	Alcohol	578 (183)	471 (180)
		Food	657 (180)	709 (283)
	Food (salty)	Salty	673 (213)	641 (256)
		Healthy	645 (189)	777 (296)
	Food (sugary)	Sugary	648 (183)	657 (249)
		Healthy	663 (193)	761 (316)

Dwell time. A main type effect was found in the drink ($F(1, 83)=6.273$, $p=0.014$, $\eta^2=0.070$), drink–food ($F(1, 83)=32.518$, $p<0.001$, $\eta^2=0.281$) and food ($F(1, 83)=4.135$, $p=0.045$, $\eta^2=0.047$) blocks, showing a longer dwell time on soft drinks and food compared to alcohol, and on healthy food compared to sugary food. Centrally, a group–type interaction was found in the drink ($F(1, 83)=5.040$, $p=0.027$, $\eta^2=0.057$), drink–food ($F(1, 83)=8.146$, $p=0.005$, $\eta^2=0.089$) and food ($F(1, 83)=6.899$, $p=0.010$, $\eta^2=0.077$) blocks. In the drink block, CTL showed a longer dwell time on soft drinks compared to alcohol ($t(42)=2.884$, $p=0.006$), while no difference was observed in BD. In the drink–food block, both groups showed a longer dwell time on food compared to alcohol (BD: $t(41)=2.523$, $p=0.016$; CTL: $t(42)=5.217$, $p<0.001$), with BD showing a smaller difference than CTL ($t(83)=2.702$, $p=0.008$). In the food block, CTL showed a longer dwell time on healthy food compared to salty ($t(42)=2.940$, $p=0.005$) and sugary food ($t(42)=2.335$, $p=0.024$), and compared to BD ($t(83)=2.445$, $p=0.017$). No significant main group effect was found in any block ($p>0.05$).

Craving analyses

Craving-related correlations. Alcohol craving was significantly correlated with dwell time on alcohol-related stimuli (drink block: $r=0.533$, $p<0.001$; drink–food block: $r=0.355$, $p<0.001$). Sugary food craving was significantly correlated with dwell time on sugary food stimuli (food block: $r=0.411$, $p<0.001$), as well as salty food craving with dwell time on salty food stimuli (food block: $r=0.365$, $p<0.001$). No correlation was found between the first AOI visited measures or RT measures and any craving type ($p>0.05$).

Craving-related regression. In the BD group, the dwell time on alcohol stimuli in the drink block was predicted by the full model (containing AUDIT, binge drinking, BDI, STAI-A, STAI-B, UPPS, and alcohol craving scores as predictors; $F(7, 41)=3.458$, $p=0.007$, $R^2_{Adj}=0.296$), but alcohol craving was the only variable significantly contributing to the prediction (β=0.510, $t=3.812$, $p=0.001$). In the drink–food block, dwell time on alcohol stimuli was also predicted by the full model ($F(7, 41)=3.162$, $p=0.011$, $R^2_{Adj}=0.270$), but here again, alcohol craving was the only predictor (β=0.306, $t=2.243$, $p=0.032$). Dwell time on food stimuli was not significantly predicted by the full model ($F(7, 41)=1.495$, $p=0.197$, $R^2_{Adj}=0.003$). In the food block, dwell time on salty food stimuli was predicted by the full model ($F(7, 41)=3.417$, $p=0.007$, $R^2_{Adj}=0.292$), with the binge-drinking score being the only significant predictor (β=0.666, $t=3.316$, $p=0.002$). Similarly, dwell time on sugary food stimuli was predicted by the full model ($F(7, 41)=3.402$, $p=0.007$, $R^2_{Adj}=0.291$), with the binge-drinking score (β=0.519, $t=2.562$, $p=0.015$) and sugary food craving (β=0.452, $t=3.230$, $p=0.003$) being the significant contributors. In the CTL group, dwell time on alcohol stimuli was predicted by the model in the drink block ($F(7, 42)=3.450$, $p=0.007$, $R^2_{Adj}=0.290$), with STAI-A (β=-0.668, $t=3.016$, $p=0.005$) and UPPS scores (β=0.705, $t=2.999$, $p=0.005$) significantly adding to the prediction. In the drink–food block, dwell times on alcohol stimuli ($F(7, 42)=1.175$, $p=0.342$, $R^2_{Adj}=0.028$) and food stimuli ($F(7, 42)=1.014$, $p=0.445$, $R^2_{Adj}=0.003$) were not predicted by the model. In the food block, the models did not significantly predict dwell time for salty food ($F(7, 42)=1.324$, $p=0.268$, $R^2_{Adj}=0.051$) and sugary food ($F(7, 42)=0.845$, $p=0.558$, $R^2_{Adj}=0.027$) stimuli. All these regression analyses are reported in the Supplemental Material.

Craving-related median split analyses

Median split procedure. Median splits were conducted in each group (BD and CTL) based on the craving scores observed for alcohol, salty and sugary food. Importantly, the resulting subgroups (i.e. BD and CTL subgroups presenting low vs. high

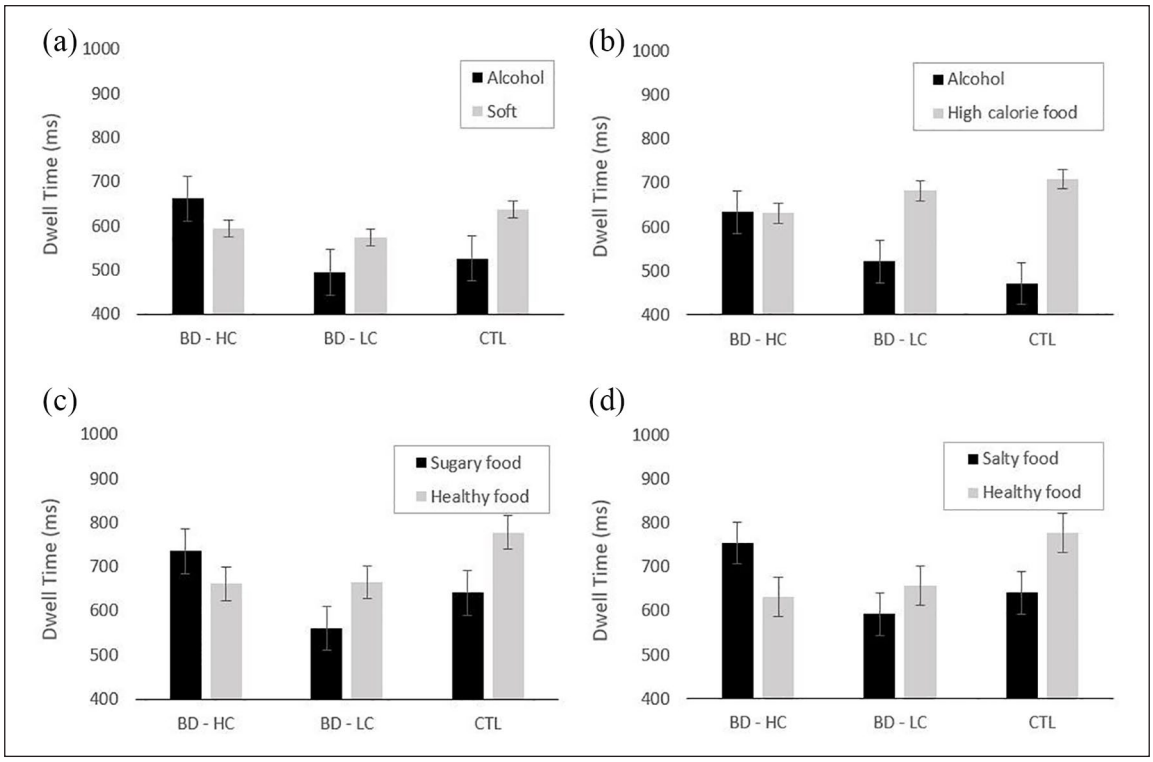

Figure 2. Dwell times observed in binge drinkers with high craving (BD – HC), binge drinkers with low craving (BD – LC) and control participants (CTL) in the drink block (a), drink–food block (b) and food block (c) for the sugary/healthy food comparison and (d) for the salty/healthy food comparison.

alcohol/salty food/sugary food cravings) did not differ regarding alcohol-related or psychopathological variables (see Supplemental Material), ensuring that the differences observed between low and high cravers were specifically related to current craving intensity.

Median split on RT. In the drink and drink–food blocks, no significant interaction was found between type and alcohol, salty or sugary food craving ($p>0.05$) in the BD and CTL groups. In the food block, an interaction between sugary food craving and type was found among BD ($F(1, 40)=5.193$, $p=0.028$, $\eta^2=0.115$), but no difference was found when comparing BD with high and low craving (healthy food: $t(40)=1.113$, $p=0.272$; unhealthy food: $t(40)=0.477$, $p=0.636$), and no difference was found in the CTL group.

Median split on first AOI visited. In the drink, drink–food and food blocks, no significant interaction was found between type and alcohol, salty or sugary food craving ($p>0.05$) in the BD and CTL groups.

Median split on dwell time. In the drink block (see Figure 2), an interaction between alcohol craving and type was found among BD ($F(1, 40)=9.122$, $p=0.004$, $\eta^2=0.186$), with the subgroup with high craving showing a longer dwell time for alcohol-related stimuli ($t(40)=3.175$, $p=0.003$). In the drink–food block, an interaction between alcohol craving and type was also found among BD ($F(1, 40)=8.007$, $p=0.007$, $\eta^2=0.167$), with the subgroup with low craving showing a longer dwell time for food stimuli ($t(40)=2.057$, $p=0.046$). No significant interaction was found for salty and sugary food craving ($p>0.05$). In the food block, an interaction between salty food craving and type was found among BD ($F(1, 40)=5.585$, $p=0.023$, $\eta^2=0.123$), with the subgroup with high craving showing a longer dwell time on salty food ($t(40)=2.629$, $p=0.012$). The same interaction was found for sugary food craving ($F(1, 40)=5.996$, $p=0.019$, $\eta^2=0.130$), with the subgroup with high craving showing a longer dwell time on sugary food ($t(40)=3.485$, $p=0.001$). Finally, a main sugary food craving effect was found in BD ($F(1, 40)=4.170$, $p=0.048$, $\eta^2=0.094$) and CTL ($F(1, 41)=9.310$, $p=0.004$, $\eta^2=0.185$), with the subgroup with high craving showing a longer dwell time. No significant interactions between alcohol/sugary/salty craving and type were found among CTL in any block ($p>0.05$).

Discussion

The presence of attentional bias towards alcohol-related cues in severe AUD has been widely established during the last decades (Field and Cox, 2008). The investigation of this bias has recently been extended to various drinking patterns, and its assessment has been improved through the use of innovative techniques. The present paper aimed to extend this research field by exploring the presence and extent of attentional bias in binge drinking using combined RT and eye-tracking measures.

Regarding RT, no general (i.e. independent of craving) attentional bias was observed in BD, as no significant difference was shown between BD and CTL in any block. This absence of RT results, contrasting with the differences found on eye-tracking

measures, supports previous studies showing that VPT based only on RT does not allow alcohol-related attentional bias to be reliably indexed in subclinical populations, whereas the complementary use of eye-tracking provides a more reliable and robust bias assessment (Marks et al., 2015; Miller and Fillmore, 2010, 2011). The internal reliability analyses performed in the present paper offered strong support to this proposal by showing a very poor reliability for RT measures (Cronbach's $\alpha < 0.2$), and conversely a very high reliability for eye-tracking indices (Cronbach's $\alpha > 0.75$), particularly for dwell time measures (Cronbach's $\alpha > 0.90$). Regarding eye-tracking results, indices reflecting the initial and early processes (i.e. first AOI visited) and the late ones (i.e. dwell time) did not demonstrate any global attentional bias towards alcohol cues in BD. This is inconsistent with most previous studies showing the presence of attentional bias in diverse subclinical populations with excessive alcohol consumption patterns (Field et al., 2004; Hallgren and McCrady, 2013; Miller and Fillmore, 2011; Townshend and Duka, 2001; van Duijvenbode et al., 2017; Weafer and Fillmore, 2013). Nevertheless, it should be noted that these earlier studies were not focusing on binge drinking habits but rather were exploring heavy drinking samples, with large variability in the alcohol consumption patterns considered and in the inclusion/exclusion criteria determined. Moreover, the present study is not the first failing to replicate these earlier findings. The only previous study focusing on binge drinking (DePalma et al., 2017) did not report any bias towards alcohol among BD for RT. In the same vein, Schoenmakers et al. (2008) did not observe a longer dwell time on alcohol-related pictures in sober heavy drinkers.

Importantly, while no dwell time difference was observed between alcohol-related and soft-drink stimuli in BD, CTL presented a higher dwell time for soft drinks, suggesting the presence of a bias towards healthier stimuli (or away from alcohol-related ones) in CTL, absent in BD. This bias should lead to reconsider the so-called alcohol-related attentional bias reported in earlier studies. For example, McAteer et al. (2015) stated the presence of an alcohol attentional bias in heavy drinkers, but this result was due to the fact that control participants showed a strong bias for neutral stimuli and not to a real alcohol-related bias in the experimental group (as dwell times for alcohol and neutral stimuli did not differ in heavy drinkers). In the present study, longer dwell time on soft-drink pictures in CTL (when compared to BD) was only observed during the latter half of the stimuli presentation. No bias was observed during early attentional processing (considered as the automatic processing stage in earlier studies), explored by first AOI visited and T1 dwell time. Similar results were observed by McAteer et al. (2015), who suggested that the automaticity of attentional bias, postulated by several theoretical models, would not be present in regular drinkers but rather would be specific to severe AUD. Actually, previous studies using RT and variations in stimuli presentation time observed an automatic capture of attention towards alcohol-related stimuli in severe AUD when stimuli were presented for 50–100 ms, while this alcohol attentional bias was only measured in regular drinkers after longer presentation times (Field et al., 2004; Noël et al., 2006). In our study, the similar patterns between groups appeared to vanish during the late processing stages, since a longer dwell time for soft drinks (when compared to alcohol-related ones) was observed for CTL and not for BD. These findings clarify the time course of attentional processing by showing that the difference between CTL and BD only appeared during the later processing stages, and are not related to an early automatic capture of attentional resources by alcohol-related stimuli, as observed in severe AUD. The absence of an early bias among BD could, however, be partly due to the classical dominance of the left side of the visual field (see Supplemental Material) related to reading/writing habits (i.e. left-gaze bias), leading the participants to orient their attention preferentially to the left side of the screen at early processing stages, regardless the type of stimuli presented on the left side (Foulsham et al., 2013; McAteer et al., 2015).

Regarding the specificity of the bias for alcohol, results indicated that BD are also strongly attracted by other appetitive stimuli as shown by results from the drink–food block (i.e. RT, first AOI visited and dwell time) which revealed that both groups were more attracted by high-calorie food when compared to alcohol. It thus appears that the potential attentional bias (beyond being present only when high craving levels are reported, as discussed below) is not specific to alcohol-related cues: BD also have a preferential allocation of attentional resources towards other appetitive stimuli, and even a stronger attraction towards high-calorie food stimuli than alcohol-related ones. Nevertheless, the higher percentage of first fixations on food (when compared to alcohol) in all participants might be partly explained by a general complexity effect, with food stimuli presenting a higher degree of visual complexity, potentially influencing the initiation of the first saccade. Future studies should thus further explore the generalisation of the bias towards other appetitive stimuli.

No attentional bias was found here in BD when considered as a homogeneous group. However, in line with earlier studies (e.g. Hobson et al., 2013), our results showed that alcohol craving widely influenced the magnitude of the bias towards alcohol-related stimuli in BD. The subgroup of high cravers presented a significant bias towards alcohol, while low cravers presented an anti-alcohol bias, as found in CTL. Attentional bias towards alcohol was thus only found among BD when combined with a high level of craving. The intensity of alcohol craving at the testing time is thus the core determinant of attentional bias magnitude in BD. This finding is in line with evidence from Field et al. (2013), who also used a median split on craving levels among alcohol-dependent individuals to show that a far stronger attentional bias was found among patients with high craving. Similarly, previous studies reported that regular drinkers with high craving presented an attentional bias towards alcohol cues, while regular drinkers with low craving did not (Field et al., 2005; Hobson et al., 2013). Hobson et al. (2013) also demonstrated that eye-tracking indices of attentional bias were related to craving but not alcohol consumption, which is consistent with the present multiple regression analysis showing that dwell time was significantly predicted by craving but not alcohol consumption or psychopathological variables. Moreover, the impact of craving on attentional bias among BD is found here when considering dwell time but not when considering the first AOI visited. The theoretical and experimental proposal, emerging from severe AUD studies, that craving influences the early attentional capture might thus not apply to binge drinking, where craving intensity would rather influence later and more controlled processes.

As a whole, these findings suggest that attentional bias observed in populations with subclinical alcohol consumption, and particularly in binge drinking, is not explained by alcohol consumption but rather by an interaction between the drinking

pattern (i.e. binge drinking) and craving level during the task. The role of craving in the intensity of attentional bias had already been suggested in earlier work (Hobson et al., 2013; Field et al., 2004, 2005), but we show here that in subclinical samples, craving levels are not merely intensifying the bias, but rather that the bias is absent among BD with low craving. At the initial stages of excessive alcohol consumption, attentional bias thus might not yet constitute a core and stable characteristic but rather would be influenced by the motivational state. This assumption is in line with the theoretical account proposed by Field et al. (2016) regarding the role of attentional bias in addictive disorders. They indeed questioned its stability and rather suggested that this bias would be determined by momentary evaluations of substance-related stimuli, which fluctuate with current motivational tendencies to consume. Interestingly, the association between craving and attentional bias has also been observed between the level of craving for salty or sugary food and the bias towards these cues. The attentional bias towards food appears in all participants with a high craving for salty or sugary food, while it only occurs in BD regarding alcohol cues. Future work should extend these results to other appetitive cues and drinking patterns (centrally by comparing BD with heavy drinkers). They should also explore the influence of other alcohol-related variables (e.g. time since last binge-drinking episode, alcohol consumption during the days preceding the experiment, withdrawal symptoms), craving-related factors (e.g. explicit liking, satiation level) and psychopathological co-morbidities (while they did not influence the experimental results, the depression and anxiety scores obtained in our sample were quite high, in line with earlier studies among university students; e.g. Beiter et al., 2015; Ibrahim et al., 2013). At the methodological level, the following points should also be underlined. First, we used identical stimuli for all participants, but variations in preferred alcohol drinks might have influenced the attentional bias. Upcoming studies should explore such influence, notably by using personalised stimuli when exploring the attentional bias among binge drinkers, as recently recommended (Christiansen et al., 2015, but see also Jones et al., 2018). Second, our design did not propose total randomisation of the experimental blocks (i.e. the drink block was systematically presented first). While this choice allowed us to have an uncontaminated measure of the classical attentional bias towards alcohol-related stimuli, it might have influenced the results observed for the drink–food block. Indeed, despite the fact that different alcohol-related stimuli data sets were presented in the drink block and drink–food block, participants had already been confronted with alcohol-related stimuli when starting the drink–food block, while food stimuli were presented for the first time. Despite these limitations, this study is the first to demonstrate that the attentional bias towards alcohol-related in binge drinking is (a) strongly determined by craving intensity and (b) not specific to alcohol, as it is also found for other appetitive cues.

Acknowledgements

We thank Gaspard Bechet for his help in data acquisition.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship and/or publication of this article: This study was supported by the grant ADi/DB/1058.2011 from the Fonds Spéciaux de Recherche of the Université catholique de Louvain (Belgium). Pierre Maurage (Senior Research Associate) and Zoé Bollen (Research Assistant) are funded by the Belgian Fund for Scientific Research (F.R.S.-FNRS, Belgium). Nicolas Masson is a post-doctoral researcher funded by grant PDR-FNRS T.0047.18 and by the National Research Fund of Luxembourg.

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Supplemental material

Supplemental material for this article is available online.

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