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ORIGINAL INVESTIGATION

Does alcohol automatically capture drinkers' attention? Exploration through an eye-tracking saccadic choice task

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Abstract

Rationale Dominant theoretical models postulate the presence of an automatic attentional bias (AB) towards alcohol-related stimuli in alcohol use disorder, such AB constituting a core feature of this disorder. An early alcohol AB has been documented in subclinical populations such as binge drinking (i.e., a drinking pattern prevalent in youth and characterized by repeated alternation between alcohol intoxications and withdrawals, generating cerebral consequences). However, the automatic nature of AB remains to be established.

Objectives We investigated the automatic nature of AB in binge drinkers through the saccadic choice task. This eye-tracking paradigm consistently highlights the extremely fast and involuntary saccadic responses elicited by faces in humans, relative to other object categories. Through an alcohol-related adaptation of the saccadic choice task, we tested whether the early and automatic capture of attentional resources elicited by faces can also be found for alcohol-related stimuli in binge drinkers, as predicted by theoretical models.

Methods Forty-three binge drinkers and 44 control participants performed two versions of the saccadic choice task. In the original version, two images (a face, a vehicle) were displayed on the left and right side of the screen respectively. Participants had to perform a saccade as fast as possible towards the target stimulus (either face or vehicle). In the alcohol-related version, the task was identical, but the images were an alcoholic beverage and a non-alcoholic stimulus.

Results We replicated the automatic attraction towards faces in both groups, as faces generated higher saccadic accuracy, speed, and amplitude than vehicles, as well as higher corrective saccade proportion. Concerning the alcohol-related adaptation of the task, groups did not differ for the accuracy, speed, and amplitude of the first saccade towards alcohol. However, binge drinkers differed from controls regarding the proportion of corrective saccade towards non-alcoholic stimuli after an error saccade towards alcohol, suggesting the presence of an alcohol disengagement bias specific to binge drinkers.

Conclusions Alcohol-related AB in binge drinkers is not characterized by an early and automatic hijacking of attention towards alcohol. This AB rather relies on later and more controlled processing stages, namely a difficulty to disengage attentional resources from alcohol-related stimuli.

Keywords Attentional bias · Binge drinking · Saccadic choice task · Saccadic response · Alcohol use disorder

Introduction

Attentional bias (AB) refers to the tendency to preferentially orient one's attentional resources towards salient or behaviorally relevant stimuli when presented in the environment. Prominent addiction models (Bechara 2005; Wiers et al. 2007) suggested that alcohol-related stimuli would hijack the attention of individuals with alcohol use disorder (AUD) through associative learning, ending up in an AB towards alcohol. The influential incentive-sensitization theory (Robinson and Berridge 1993) notably posits that repetitive alcohol exposures sensitize the reward system, thus enhancing the motivational properties

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(i.e., incentive salience) of the stimuli associated with alcohol use. Becoming more salient, these alcohol-related stimuli automatically and rapidly grab drinker's attention and result in AB. This theory was then refined by a psychopharmacological model (Franken 2003), suggesting that, when alcohol-related stimuli are present in the environment, they increase the dopaminergic response in the reward circuit, which in turn serves to automatically capture one's attention towards those stimuli. Such alcohol AB is thought to have clinical consequences, as it would increase craving (i.e., the intense urge and desire to consume alcohol), favor increased alcohol consumption, and enhance relapse risk. Hence, AB would play a crucial role in the onset and persistence of AUD and is now considered a key process in this disorder. Indeed, current prominent models postulate that the over-sensitivity of the reward system, caused by repeated alcohol use, makes the user highly reactive to alcohol-related stimuli, this AB being considered an early, automatic, and uncontrollable hijacking of attentional resources.

However, the empirical evidence supporting such strong theoretical assumptions remains limited in AUD. Previous behavioral studies showed very heterogeneous findings regarding the presence and extent of AB in the classical population of interest, namely recently detoxified patients with severe AUD (for a review, see Bollen et al. 2022). Indeed, some findings revealed the presence of AB in this clinical population (e.g., Müller-Oehring et al. 2019), but others rather revealed an avoidance pattern (e.g., Townshend and Duka 2007), and most did not show any difference in the attentional processing of alcohol-related stimuli compared with control individuals presenting low/moderate alcohol consumption (e.g., Field et al. 2013; Wiers et al. 2016). These disparate findings might be partly explained by the heterogeneity (e.g., various stimuli presentation times) and low reliability (due to reaction time measures; Ataya et al. 2012) of the AB paradigms used, as well as by the lack of inclusion criteria (e.g., alcohol doses per week) for recruiting healthy controls. The presence of alcohol-related AB appears more consistent in subclinical populations (i.e., individuals presenting excessive alcohol consumption but who do not present the diagnosis of severe AUD), since AB was positively related with alcohol use intensity in most studies conducted among social drinkers (Albery 2015; Field et al. 2011) and was found to be stronger in more specific drinking patterns (e.g., heavy or binge drinkers) compared to light drinkers (DePalma et al. 2017; Tibboel et al. 2010), especially in the presence of high subjective craving (Bollen et al. 2020). Nevertheless, the inter-study comparison is dampened by a lack of coherence regarding the terminology and inclusion criteria to characterize these drinking patterns. To address this issue, we will focus on binge drinking, because it constitutes a clearly defined and specific drinking pattern (Maurage et al. 2020) and because it has been repeatedly associated with alcohol AB (Elton et al. 2021; Langbridge et al. 2019), thus constituting the ideal population to reliably test the features of AB in a subclinical population. Popular in youth, binge drinking is characterized by intense alcohol consumptions in short periods of time to reach drunkenness (Lannoy et al. 2021). The repeated alternation between intense intoxications and withdrawal periods appears particularly harmful for the brain, leading to well-established neuropsychological and cerebral negative effects (Crego et al. 2009; Lannoy et al. 2019; López-Caneda et al. 2013). The definition criteria for binge drinking usually rely on the computation of a binge drinking score evaluating the key characteristics of this habit: consumption speed, drunkenness frequency, and drunkenness ratio per drinking occasions (Townshend and Duka 2002).

As mentioned above, a key models' assumption is that AB towards alcohol is early, involuntary, and automatic. To date, studies focusing on the time course of AB in subclinical populations revealed, however, that it mostly appears at later and more controlled attentional stages (Bollen et al. 2022). For example, Field et al. (2004) reported an alcohol-related AB (i.e., shorter reaction times for probes appearing on the side of the screen previously occupied by alcohol-related stimuli) in heavy drinkers (compared to light drinkers) when using the visual probe task, but only for stimuli with longer presentation duration (i.e., 500–2000 ms versus 200 ms). The maintenance of attention towards alcohol was also reflected by specific assessments of disengagement processes of AB through alternative paradigms (see Bollen et al. 2022 for a detailed description): the spatial cueing task, the odd-one-out task, and the selective attention/action-tendency task (Gladwin et al. 2013; Heitmann et al. 2020; Sharbanee et al. 2013). Such findings suggested that AB would be characterized by a difficulty to disengage attention from alcohol-related stimuli once detected, potentially caused by the disrupted activity of higher-level and controlled processes (i.e., inhibitory control, executive functions; Carbia et al. 2018; Lees et al. 2019; López-Caneda et al. 2014). The automaticity in AB, postulated by dominant models, thus appears questionable in these populations. Some discrepancies were however found regarding the time course of AB when focusing on binge drinkers. Indeed, binge drinkers showed delayed interferences for color-naming alcohol-related words in an alcohol Stroop task, reflecting an AB at later and more controlled stages of processing (Hallgren and McCrady 2013), but were more efficient to process alcohol-related cues at early encoding levels in an attentional blink task, reflecting more automatic AB processes (DePalma et al. 2017; Elton et al. 2021). A major limitation of these previous studies is that they exclusively relied on behavioral measures (i.e., manual reaction time) showing very low reliability (Ataya et al. 2012). Beyond the issue that such measures relied on hand movements and could thus be biased by potential deficits in motor responses, inferring AB through manual reaction time raises concerns since it only provided information about where participants focused their attention at the specific time of probe onset, without indexing the global stream and successive steps of attentional processing involved in AB (Field and Cox 2008). Therefore, their methodology did not allow determining whether this bias relies on a genuine automatic hijacking of the attentional resources by alcohol or whether it is rather characterized by an increase in the controlled processing of alcohol-related stimuli when consciously perceived.

To address this issue, recent studies used neuroscience tools to determine the neural activation underlying the different processes of alcohol-related AB. For example, the study of brain electrical activity through electroencephalogram (EEG) allows to measure the neurofunctional brain response evoked by alcohol-related stimuli with high temporal resolution, thus providing major insights on the early brain processes involved when exposed to alcohol-related stimuli (Almeida-Antunes et al. 2022). Most EEG studies reported consistent findings by showing higher alcohol-related cue reactivity and altered inhibitory processes (e.g., Blanco-Ramos et al. 2019; Petit et al. 2012; Ryerson et al. 2017). Nevertheless, this method does not allow to investigate the specific processes involved in the preferential allocation of attentional resources towards alcohol-related stimuli when confronted with neutral ones. Recent studies thus used eye-tracking measures to directly and precisely assess and distinguish the successive cognitive processes underlying AB, by detecting eye movements and gaze positions with a high temporal and spatial resolution throughout the task (Popa et al. 2015). Whereas manual reaction times only offer an indirect AB measure (i.e., the final processing output), eye-tracking allowed deepening the understanding of the time course and core mechanisms of AB and enhancing the reliability of its assessment (Bollen et al. 2020; Christiansen et al. 2015). Eye-tracking findings suggested the presence of alcohol-related AB in subclinical populations (e.g., heavy or regular drinkers) at later processing stages, as indexed by longer dwell times (i.e., overall fixation time) or higher number of fixations towards alcohol-related stimuli (e.g., McAteer et al. 2015, 2018; Monem and Fillmore 2017). While these studies did not index any early AB (e.g., alcohol preference in the first fixation), they used free exploration tasks with relatively long presentation times and without any "attentional task" per se, which does not make them suitable for measuring the early and automatic capture of attention by alcohol-related stimuli. To date, only one study (Bollen et al. 2020) has explored the time course of AB in a specific population of binge drinkers, by combining the visual probe task with eye-tracking. They documented an AB among binge drinkers with high current craving, this bias being related to late controlled attentional stages (i.e., longer dwell times for alcohol-related stimuli compared to neutral ones). However, the visual probe task is usually characterized by long stimuli presentation duration before the appearance of the probe, with participants not receiving any specific instruction on how to process these stimuli, thus potentially masking the early processing stages of AB. The present study will overcome this limit through a paradigm specifically dedicated to the exploration of early and automatic AB, namely the saccadic choice task, which will allow the first specific exploration of AB automaticity.

This paradigm was initially developed to explore the speed of visual processing (Kirchner and Thorpe 2006) and was later adapted to address the speed of face processing (Crouzet et al. 2010). Indeed, human faces are naturally salient stimuli automatically capturing attention at very early processing stages. In this saccadic choice task, two images, a target (e.g., a face) and a distractor (e.g., a vehicle), are simultaneously displayed on the left and right of the screen. Participants have to perform a saccade as fast as possible towards the target stimulus. Studies have repeatedly reported shorter saccadic latencies when the target is a face (minimum saccadic reaction times of 100–120 ms for face targets vs. 130–150 ms for other target categories, e.g., vehicles), demonstrating the presence of a very strong automatic bias for faces compared to other stimuli (Crouzet et al. 2010; Guyader et al. 2017; Kauffman et al. 2019; 2021). Furthermore, they also reported that participants made more error saccades (i.e., saccades towards the distractor) when the distractor was a face than when it was another stimulus. These experimental results suggest that fast saccades towards attention-grabbing stimuli (i.e., faces) are automatic and beyond voluntary control. It should however be noted that other paradigms that directly involved more controlled processes (e.g., the antisaccade task) led to different results, notably reporting that facial stimuli are easier to avoid (i.e., generate stronger inhibitory control) than circles or scrambled facial stimuli (Hoffmann et al. 2021). The saccadic choice task constitutes an ideal paradigm to explore the early preferential processing of specific stimuli. This is further illustrated by the fact that, after an error saccade in this task, participants present more frequent and faster corrective saccades (i.e., second saccades directed towards the target when first saccades were directed towards the distractor) when the target is a face (indexing a re-engagement bias towards faces) than when it is another stimulus (indexing a disengagement bias from faces, Kauffmann et al. 2019). Finally, they explored the amplitude (i.e., distance between the saccadic starting and ending points) of the saccade and observed larger saccades directed towards faces (either as target or distractor; Kauffmann et al. 2019), suggesting that the content of the stimuli influences the programming of saccade amplitude prior to its execution. As a whole, the saccadic choice task constitutes a powerful paradigm to test the early, automatic, and involuntary capture of attentional resources by salient stimuli, and thus the presence of an AB towards such stimuli.

We thus used an adapted version of the saccadic choice task with alcohol-related stimuli to explore the automatic aspects of alcohol-related AB. If theoretical models' assumptions are correct, alcohol-related stimuli should hijack attentional resources and generate the same response pattern than the one reported above for faces (i.e., shorter saccadic latencies, increased error saccades when alcohol-related stimuli are the distractor, re-engagement and disengagement biases). We investigated this assumption in binge drinkers, since the presence of AB has been more consistently reported in subclinical populations than among patients diagnosed with severe AUD. The advantages of the saccadic choice task are multiple. First, it is combined with eye-tracking, thus offering more reliable AB measures than manual reaction times. Second, it uses very short stimuli presentation times, thus forcing participants to perform their saccade towards stimuli as fast as possible and providing more insights regarding the early processes of AB compared to paradigms with longer presentation times. Finally, the assessment of the first saccades and the corrective ones offers important insights on the engagement, disengagement, and re-engagement aspects of AB. We firstly administered the original version of the saccadic choice task to all participants to ensure the absence of any attentional dysfunction for the detection of highly salient stimuli in binge drinkers. The simultaneous use of both the original and the adapted alcohol version of the task led to two hypotheses: (1) binge drinkers and control participants will present the classical automatic capture of attention by universally salient stimuli (i.e., faces); (2) this automatic AB will also be present for alcohol-related stimuli among binge drinkers (but not among control participants), as these stimuli are supposed to acquire incentive salience in this population (Robinson and Berridge 1993).

Methods

Participants

We recruited participants via an online screening survey sent through social networks to students from UCLouvain (Belgium). Participants had to fill in questionnaires assessing alcohol-related disorders (Alcohol Use Disorders Identification Test, AUDIT; Saunders et al. 1993; French validation: Gache et al. 2005), binge drinking habits (i.e., consumption speed, drunkenness frequency and ratio, number of binge drinking episodes (i.e., drinking more than 6 units) per week), socio-demographic (e.g., age, sex), and other alcohol consumption variables (i.e., number of alcohol units consumed per week, number of units per occasion, number of drinking occasions per week). Before completing them, they were provided with information about equivalences in terms of the number of alcohol units per type of alcoholic beverages (an alcohol unit corresponding to 10 gr of pure ethanol in Belgium). To be included in the study, they had to meet the following criteria: absence of parental history of severe AUD, absence of current or past psychological or neurological disorders, and normal or lens corrected vision.

For each participant, we then computed the binge drinking score (Townshend and Duka 2005) by using the following formula: $(4 \times \text{consumption speed}) + \text{drunkenness frequency} + (0.2 \times \text{drunkenness ratio})$. We recruited 44 binge drinkers (BD; AUDIT score ≤ 20; binge drinking score ≥ 24; 2–4 drinking occasions per week; binge drinking episodes per week ≥ 1), and 45 control participants matched on gender (CTL; AUDIT score ≤ 8; binge drinking score ≤ 16; units per week ≤ 10; units per occasion ≤ 3; no binge drinking episodes). Regarding the sample size determination, no reliable a priori power computation was possible as this study was the first using the saccadic reaction time with alcohol-related stimuli in a subclinical population. We thus decided to include a larger sample size per group than all previous studies using this paradigm with facial stimuli among healthy populations (Kauffmann et al. 2019; 2021), to increase our ability to detect smaller effects of alcohol-related stimuli in the second task.

All participants provided their informed written consent before taking part in the study and were not aware of the hypotheses tested. We performed the study protocol in accordance with the ethical standards established by the Declaration of Helsinki for experiments involving humans, and the Ethics Committee of the Psychological Sciences Research Institute (UCLouvain) approved it.

We asked participants to refrain from consuming alcohol during the day preceding the experimental session, and we questioned them about their recent consumption before starting the experiment.[1] Before performing the two experimental tasks, we asked participants to fill in questionnaires using Qualtrics software (Qualtrics, LLC), assessing state anxiety (STAI-A) and current alcohol craving (Alcohol Craving Questionnaire Short Form Revised, ACQ-SF-R and Craving Visual Analogue Scale, C-VAS: "Indicate how much you want to drink alcohol right now (from 0 = not wanting at all, to 100 = terribly wanting)"). To control for psychopathological comorbidities, they filled in other questionnaires between the tasks assessing depressive symptoms (Beck Depression

[1] We performed correlations between alcohol consumption during the day before the experiment (i.e., number of alcohol units) and alcohol-related AB, since previous studies showed that acute alcohol consumption could induce alcohol-related AB in social drinkers (Duka & Townshend, 2004). For the alcohol vs. flower task, results showed no correlation with the accuracy of the first saccade ($r = .180$, $p = .103$), the proportion of corrective saccade ($r = .148$, $p = .183$), the latency of the first saccade ($r = -.087$, $p = .432$), or the latency of the corrective saccade ($r = .113$, $p = .307$).

Inventory, BDI-II; French validation: Beck et al. 1998) and anxiety (State-Trait Anxiety Inventory, STAI A-B; French validation: Bruchon-Schweitzer and Paulhan 1993). At the end of the experiment, we debriefed participants, who received financial compensation.

Stimuli

Stimuli were 128 colored pictures depicting human faces, vehicles, alcoholic beverages, or flowers with context (32 pictures of each category), extracted from the free-from copyright "Pixabay" stock image base (https://pixabay.com/) under CC0 License. We chose the faces, vehicles, and flower pictures from the stimuli used in Kauffman et al. (2019; 2021) that were matched on perceptual features such as luminance and RMS contrast.[2] Faces were presented with vehicle pictures to replicate the version of the saccadic choice task used in Kauffmann et al. (2019). In the alcohol saccadic choice task, we chose flower pictures as neutral stimuli instead of non-alcoholic beverage pictures since they sufficiently differ from alcoholic beverages in terms of shape and are not related with alcohol through associative learning, contrarily to non-alcoholic beverages (e.g., orange juice might hijack attentional resources through its visual similarity with alcoholic cocktails). Moreover, we conducted preliminary tests showing that the use of flower stimuli compared with alcohol stimuli facilitated the categorization of the two stimuli, resulting in a similar level of difficulty than the initial *face vs. vehicle* task, thus increasing the comparability across tasks. Finally, a previous study comparing face with flower pictures in a saccadic choice task showed that they were appropriate neutral stimuli as they elicited similar saccadic performance than vehicle pictures and did not contain features salient enough to capture attention like faces (Kauffmann et al. 2021). All pictures were matched on size (600 × 600 pixels; 11 × 11° visual angle) and spatial position of the main object in the picture.

Procedure

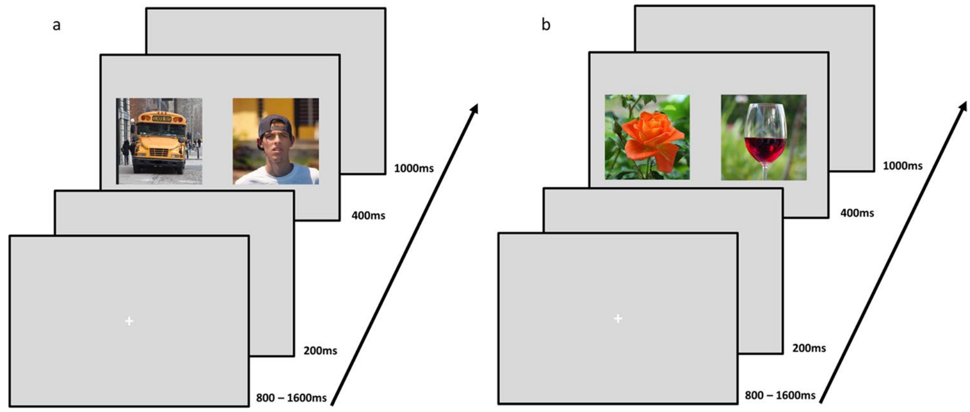
Stimuli were displayed using the Psychtoolbox (Brainard 1997; Pelli 1997) implemented in MATLAB R2021a (MathWorks, Natick, MA, USA) against a gray background (luminance of 0.44). Participants seated on a desk chair placed 60 cm away from an Asus Display Laptop PC equipped with a 17.3-inch FHD screen (resolution 1080 × 1920 pixels; refresh rate 120 Hz) and facing an eye tracker camera. We used a chinrest to stabilize participants' head position, and we recorded eye movements using the pupil-corneal reflection and remote mode of an EyeLink Portable Duo eyetracker (SR Research, Canada; sampling rate of 1000 Hz; average accuracy range 0.25–0.5°, gaze tracking range of 32° horizontally, 25° vertically). Eyelink software automatically detected saccades with the following thresholds: speed > 30°/s, acceleration > 8000°/s2, and saccadic displacement > 0.15°. Blinks were detected during partial or total occlusion of the pupil. A 9-point calibration of participant's eye gaze position was set up at the beginning of each block.

All participants completed two experimental phases consisting of the *face vs. vehicle* saccadic choice task and the *alcohol vs. flower* saccadic choice task. They received verbal instructions to perform the tasks, without being informed about their rationale. All participants systematically started by performing the *face vs. vehicle* saccadic choice task, which was replicated from Kauffmann et al. (2019, 2021) and Guyader et al. (2017). The task comprised two blocks, one for which the targets were images containing human faces (the distractors being vehicle images) and the other one for which the targets were images containing vehicles (the distractors being human face images). In a second phase, participants underwent the *alcohol vs. flower* saccadic choice task, with one block presenting alcoholic beverages as targets (and flowers as distractors) and the other block presenting flowers as targets (and alcoholic beverages as distractors). We asked participants to make a saccade as fast as possible towards the target image. We counterbalanced the order of blocks within the tasks to avoid potential learning and/or training effects.

At the beginning of each trial, a white fixation cross subtending 0.73° of visual angle was displayed centrally on a gray background screen (mean luminance of 0.5 for pixel intensity values between 0 and 1). We used the fixation cross as drift check to confirm the reliability of the eye-gaze calibration. This instruction ensured that participants initially focused their visual attention at the center of the screen in each trial. We carried out a drift correction every ten trials. The fixation cross was followed by a gap (mean gray-level screen) of 200 ms. Two images (a target and a distractor) were then simultaneously displayed on the left and right side of the central fixation cross for 400 ms. The center of each image was lateralized at 8° from the screen center. The inter-trial interval (uniform gray background) was fixed at 1000 ms (Fig. 1). Each block comprised 64 trials, with each image being presented twice, once on the left side and once on the right side, randomly. Each block lasted approximately 5 min and the total experimental task lasted 20 min.

[2] Alcohol-related pictures presented higher relative luminance (0.51 ± 0.12 vs. 0.42 ± 0.12; t_{62} = 2.943, p = .005, d = .736) than flower pictures, but they were matched on RMS contrast (p = .394). This resulted in 72% of trials containing a pair of stimuli with alcohol-related pictures showing higher relative luminance than flower pictures. This difference however did not interfere with participants' performance, as saccadic reaction time of the first saccade did not correlate with the relative luminance of the picture fixated (r = − .060, p = .576).

Fig. 1 Time course of a trial in the *face vs. vehicle* (**a**) and *alcohol vs. flower* (**b**) saccadic choice tasks



Statistical analyses

We performed the same data reduction procedure than Kauffmann et al. (2021) by removing trials in which (1) a blink occurred during stimulus presentation, (2) saccadic latencies were shorter than 50 ms, (3) saccades were initiated from more than 2° around the fixation cross, (4) saccades had an amplitude below 1°, or (5) saccade durations were above 100 ms. These criteria were based on the distributions of eye movement parameters consistently reported in the literature (e.g., Devillez et al. 2020). This procedure resulted in removing two participants (1 BD, 1 CTL), as more than half of their trials were invalid (due to poor calibration), and discarding 8.38% of the trials from the remaining participants. It should be noted that the percentage of remaining trials was similar between groups (BD: 92.59 ± 0.06%; CTL: 90.68 ± 0.08%; $t_{85} = 1.219$, $p = 0.226$) and was higher than those reported in previous studies using the same paradigm, thus ensuring the validity of our experimental procedure. We performed all statistical analyses using MATLAB R2021a (MathWorks, Natick, MA) and R (R Core Team, 2021).

We performed between-group comparisons (i.e., independent t-tests) on demographic, psychopathological characteristics and alcohol consumption variables. We analyzed the error rate (percentage of erroneous saccadic movement), latency (in milliseconds from the onset of stimuli—also called saccadic reaction time, SRT), and amplitude (distance between the positions of the start and the end of saccades, in degrees of visual angle) of the first saccade. We also examined whether erroneous first saccades were followed by corrective saccades. When applicable, we analyzed the proportion (%) and SRT of corrective saccades. We considered saccades as corrective if they ended on the target side of the display. For both tasks (*face vs. vehicle*, *alcohol vs. flower*), we performed analyses of covariance (ANCOVAs) with target (alcohol or face, flower or vehicle) as within-subject factor, group (BD, CTL) as between-subject factor and age as covariate (as age differed across groups, see below). We performed them on eye-tracking measures related to the first saccade (accuracy, SRT, amplitude) and the corrective saccade (proportion, SRT) when applicable. We conducted post hoc tests (independent samples t-tests) for the interpretation of significant target × group interactions. We estimated effect sizes by calculating partial eta-squared (η_p^2) for ANCOVAs and Cohen's d for post hoc t-tests. We also reported in Supplementary material (1) results for the *alcohol vs. flower* task when including only control participants with AUDIT score ≤ 4 to exclude any women participants with potential risky drinking, (2) methods and results regarding the minimum SRT for both tasks, and (3) methods and results for the exploratory correlations between eye-tracking measures (i.e., accuracy and SRT of the first saccade, proportion of corrective saccades) and alcohol consumption (i.e., AUDIT and binge drinking scores, craving).

Results

Demographic, psychopathological, and alcohol-related measures

As shown in Table 1, binge drinkers were younger ($t_{85} = 2.288$, $p = 0.025$, $d = 0.491$) and reported higher craving as assessed through VAS ($t_{84} = 3.096$, $p = 0.003$, $d = 0.668$) or ACQ ($t_{84} = 4.156$, $p < 0.001$, $d = 0.896$) than controls. Groups did not significantly differ regarding gender ratio ($\chi^2_{2,87} = 0.988$, $p > 0.500$), state anxiety ($p = 0.580$), trait anxiety ($p = 0.087$), and depression ($p = 0.295$).

Face vs. vehicle saccadic choice task (Fig. 2)

Accuracy

The 2 × 2 ANCOVA on mean error rates for the first saccade revealed a main effect of target ($F_{1,84} = 88.78$, $p < 0.001$, $\eta_p^2 = 0.514$). Participants made significantly less error saccades when the target stimulus was a face (14.05 ± 8.96%) than when it

Table 1 Group differences on demographic, psychopathological, and alcohol consumption measures (mean ± standard deviation) between binge drinkers (BD) and control participants (CTL)

	BD (*N* = 43)	CTL (*N* = 44)	*t or* χ^2	*p-value*
Demographic measures				
Sex ratio (female/male)	24/19	24/20	.989	.610
Age	20.88 ± 1.94	22.07 ± 2.80	2.298	.024
Psychopathological measures				
Beck Depression Inventory	5.21 ± 4.26	4.28 ± 3.92	1.054	.295
State Anxiety Inventory	33.53 ± 10.02	32.44 ± 8.15	.555	.580
Trait Anxiety Inventory	43.56 ± 10.26	39.86 ± 9.54	1.731	.087
Alcohol consumption measures				
Alcohol use disorder identification test	15.65 ± 6.02	3.36 ± 2.10	12.645	< .001
Binge drinking score	43.27 ± 21.22	5.64 ± 4.13	11.419	< .001
Craving (Visual Analogue Scale)	18.30 ± 18.59	7.58 ± 13.04	3.096	.003
Craving (Alcohol Craving Questionnaire)	31.77 ± 11.22	22.63 ± 9.06	4.156	< .001

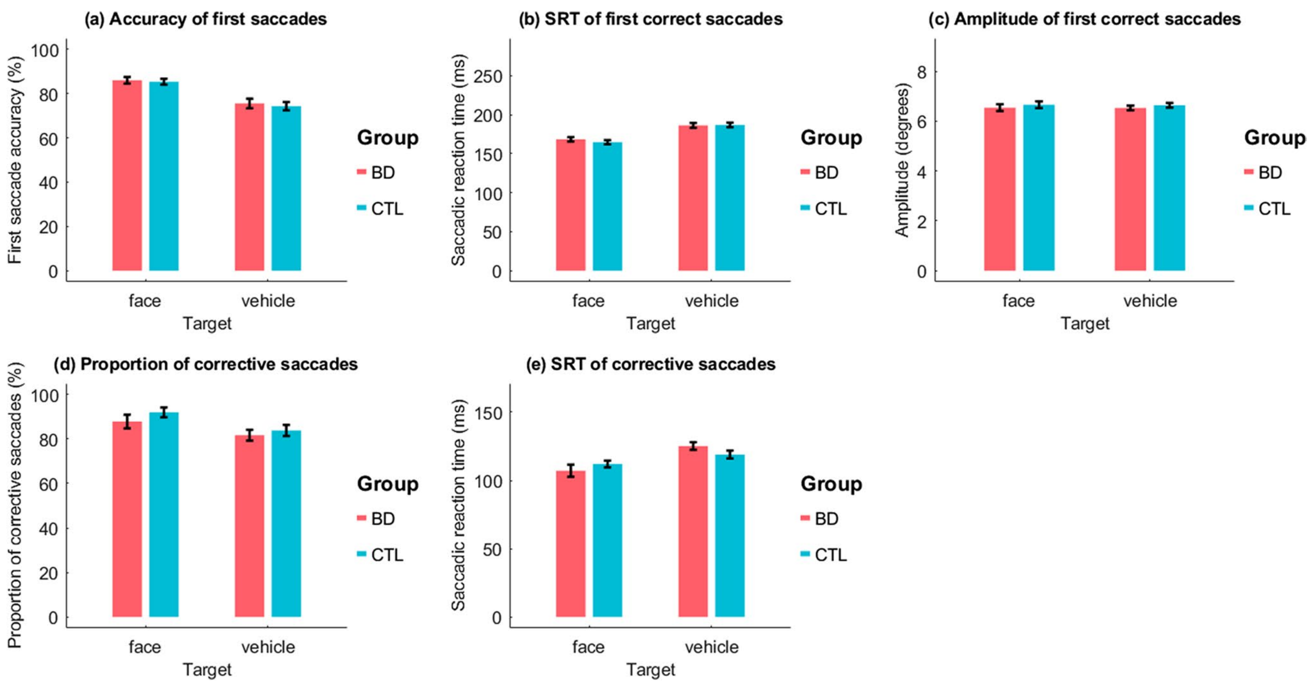


Fig. 2 **a** Mean accuracy (in percentage of correct saccadic responses) of the first saccades, **b** mean latency or saccadic reaction time (in milliseconds) of the first correct saccades, **c** mean amplitude (in degrees) of the first correct saccades, **d** mean proportion of corrective saccades, and **e** mean latency or saccadic reaction time (in milliseconds) of corrective saccades according to the target category (face, vehicle) and the group (BD, CTL). Error bars correspond to ± 1 *SE*

was a vehicle (24.61 ± 12.94%). We observed neither group effect ($p = 0.644$), nor interaction between group and target ($p = 0.589$).

Latency and amplitude of the correct first saccade

The 2 × 2 ANCOVA on mean SRT for the correct first saccade showed a main effect of target ($F_{1,84} = 139.22$, $p < 0.001$, $\eta_p^2 = 0.624$). Participants initiated their correct first saccade faster when the target stimulus was a face (180 ± 20 ms) than when it was a vehicle (203 ± 26 ms). We observed neither group effect ($p = 0.578$), nor interaction between group and target ($p = 0.657$). The 2 × 2 ANCOVA on mean amplitude for the correct first saccade showed a main effect of target ($F_{1,84} = 124.95$, $p < 0.001$, $\eta_p^2 = 0.598$). Participants performed a longer correct saccade when the target stimulus was a face (7.62 ± 0.53°) than when it was a vehicle (7.03 ± 0.72°). We observed neither group effect ($p = 0.237$), nor interaction between group and target ($p = 0.986$).

Proportion and latency of the corrective second saccade

The 2×2 ANCOVA performed on proportion of corrective saccades revealed a main effect of target ($F_{1,82}=5.08$, $p=0.027$, $\eta_p^2=0.058$). Participants made significantly more corrective saccades when the target stimulus was a face (89.97±17.73%) than when it was a vehicle (83.72±15.27%). We observed neither group effect ($p=0.404$), nor interaction between group and target ($p=0.775$). The 2×2 ANCOVA performed on mean SRT for the corrective saccade revealed a main effect of target ($F_{1,82}=20.41$, $p<0.001$, $\eta_p^2=0.201$). Participants initiated their corrective saccade faster when the target stimulus was a face (110±23 ms) than when it was a vehicle (122±19 ms). We observed neither group effect ($p=0.737$), nor interaction between group and target ($p=0.064$).

Alcohol vs. flower saccadic choice task (Fig. 3)

Accuracy

The 2×2 ANCOVA on mean error rates for the first saccade revealed no main effect of target ($p=0.276$), group ($p=0.599$), or interaction between these two factors ($p=0.849$).

Latency and amplitude of the correct first saccade

The 2×2 ANCOVA on mean SRT for the correct first saccade showed a main effect of target ($F_{1,84}=7.51$, $p=0.007$, $\eta_p^2=0.082$). Participants initiated their correct first saccade faster when the target stimulus was an alcoholic beverage (191±26 ms) than when it was a flower (197±27 ms). We observed neither group effect ($p=0.573$), nor interaction between group and target ($p=0.987$). The 2×2 ANCOVA on mean amplitude for the correct first saccade showed no main effect of target ($p=0.726$), group ($p=0.194$), or interaction between these two factors ($p=0.157$).

Proportion and latency of the corrective second saccade

The 2×2 ANCOVA performed on proportion of corrective saccade revealed a significant interaction between target and group ($F_{1,84}=5.96$, $p=0.017$, $\eta_p^2=0.066$). Post hoc independent sample t-tests showed that binge drinkers made fewer corrective saccades than controls when the target stimulus was a flower (BD: 63.15±22.22%; CTL: 73.71±21.61%; $t_{85}=2.248$, $p=0.027$, $d=0.482$), but groups did not differ when the target stimulus was an alcoholic beverage ($p=0.868$). We observed neither target ($p=0.401$)

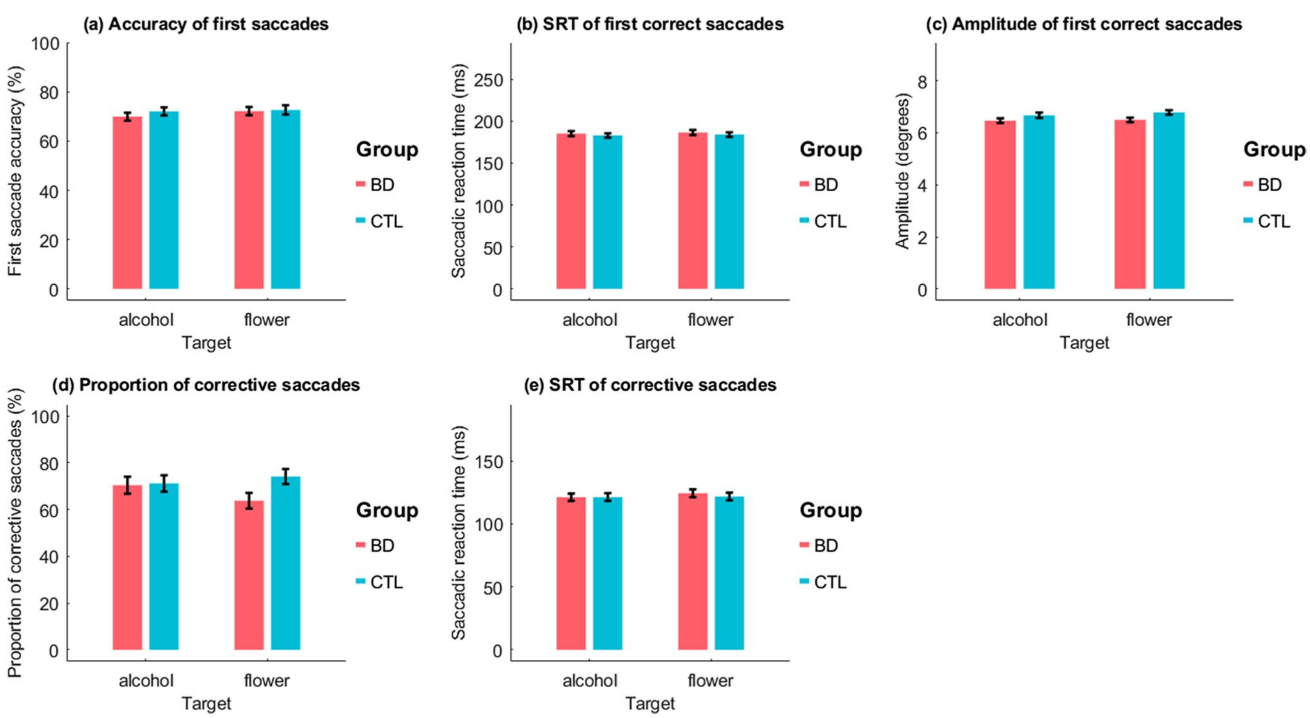


Fig. 3 **a** Mean accuracy (in % of correct saccadic responses) of the first saccades, **b** mean latency or saccadic reaction time (in milliseconds) of the first correct saccades, **c** mean amplitude (in degrees) of the first correct saccades, **d** mean proportion of corrective saccades, and **e** mean latency or saccadic reaction time (in milliseconds) of corrective saccades according to the target category (alcohol, flower) and the group (binge drinkers, controls). Error bars correspond to ±1 SE

nor group ($p = 0.322$) effects. The 2×2 ANCOVA performed on mean SRT for the corrective saccade revealed no main effect of target ($p = 0.462$), group ($p = 0.971$), or interaction between these two factors ($p = 0.815$).

Discussion

Dominant theoretical models hypothesized the presence of an automatic AB towards stimuli with acquired salience (e.g., alcoholic beverages) in chronic drinkers. Such bias is not consistently documented in the literature, since previous studies showed heterogeneous findings among individuals with severe AUD (Bollen et al. 2022). While the literature is more consistent in subclinical populations, most studies showing the presence of an alcohol-related AB, its automaticity remains to be proven. We thus applied the saccadic choice paradigm, commonly used to evaluate AB towards faces, in a population of binge drinkers and matched controls to investigate the automatic aspects of the alcohol-related AB.

First, we replicated previous findings regarding AB towards faces, since both groups processed these stimuli more rapidly and efficiently compared to vehicles (Guyader et al. 2017; Kauffmann et al. 2019; 2021). Indeed, they made less incorrect saccades and performed quicker and larger first saccades when the target was a face than when it was a vehicle. Corrective saccades were also more frequent and rapid when faces were the targets. By replicating these findings in both binge drinkers and control participants, we showed that (1) saccadic choice task constitutes a valid eye-tracking paradigm to evaluate the automatic nature of AB, and (2) binge drinkers have an automatic preference for processing faces similar to control participants, and do not present any generalized dysfunction of the impulsive/reward system responsible for the detection of salience (Franken 2003). The similar performance between groups is in line with King and Byars (2004), who showed that heavy drinking habits did not impact the saccadic latency and velocity measured in a prosaccade task.

Second, in contradiction with theoretical models' predictions, we found no early, automatic, and involuntary hijacking of attention provoked by alcohol-related stimuli (indexed by the accuracy and latency of the first saccade) specific to binge drinkers, since our findings revealed shorter SRT for alcohol-related stimuli in both groups. Whereas our findings regarding facial stimuli clearly demonstrate the saccadic choice task as an appropriate measure of the automatic hijacking processes related to AB, further research could explore the involuntary aspects of attentional processing by using other paradigms and/or measures. For example, other saccadic paradigms are known to explicitly request to inhibit saccadic responses towards alcohol when no second stimulus is on the target side of the screen, thus directly involving both automatic and controlled processes (e.g., antisaccade task; Hoffmann et al. 2021). In the same line, recent studies investigated the interaction between automatic (e.g., alcohol cue-reactivity) and controlled (e.g., inhibition abilities) processes in binge drinkers at the electrophysiological level, thus providing important insights on the underlying processes of the mechanisms related to AB (i.e., alcohol-related cue-reactivity; Almeida-Antunes et al. 2022; Blanco-Ramos et al. 2019; Lannoy et al. 2020). Beyond these perspectives, our findings already showed that binge drinkers had more difficulty to disengage from alcohol-related stimuli when their gaze was erroneously directed towards alcohol. Indeed, they corrected less frequently their saccade than control participants after having performed an error first saccade towards alcohol-related stimuli when the target was a flower, revealing the presence of a late and controlled disengagement bias related to alcohol cues. While the presence of a disengagement bias in subclinical drinkers was already demonstrated in previous studies (Gladwin et al. 2013; Heitmann et al. 2020; Sharbanee et al. 2013), we strengthen these findings through the use of an eye-tracking paradigm in a specific population of binge drinkers.

These joint results thus demonstrate that AB in binge drinkers is not characterized by an automatic capture of attention by alcohol-related cues but by an increased willingness to process these cues once detected. In line with previous studies (Field et al. 2004; Hallgren and McCrady 2013), we thus suggest that alcohol-related AB relies on late and controlled processes rather than early and automatic ones. The different effect between faces and alcoholic beverages might be partly explained in terms of differential exposure and behavioral relevance between these two classes of stimuli during life. Faces stimuli are salient for humans since the very beginning of life, as the human brain requires to quickly detect and preferentially process those socially relevant stimuli to interact with other individuals. Conversely, the increased salience properties of alcohol-related stimuli would result from repeated alcohol exposures and are thus acquired through alcohol-related experiences (Robinson and Berridge 1993). As we tested young binge drinkers who have been usually drinking for a few years only, alcohol-related AB might thus not have achieved an automatic stage yet. Future research should test the automatic aspects of alcohol-related AB in individuals with severe AUD, since this population has been exposed to excessive and chronic alcohol consumption for a longer time and might thus have developed an automatic capture of attention for alcohol-related stimuli. Nevertheless, this remains to be established as most previous studies did not show any strong and stable AB among patients with severe AUD compared to light drinkers, some of them even revealing an avoidance AB (Bollen et al. 2022). While the aim of this study was to determine whether the automatic AB for faces could also be found for alcohol-related stimuli in binge drinkers, future studies should also directly compare the attractiveness of faces *versus* alcoholic beverages by confronting these two types of stimuli in different populations of drinkers. Indeed, alcohol-related stimuli could reduce or counter the AB towards faces, although our results suggest that the incentive salience of alcohol is much lower than the one for faces in binge drinkers.

Limitations

First, whereas the number of trials per block chosen in previous studies using the saccadic choice task (Guyader et al. 2017; Kauffmann et al. 2019; 2021) was sufficient to explore AB towards highly attractive stimuli like faces, it might have been too small to detect more subtle effects from less salient stimuli like alcoholic beverages. Second, the shorter SRT for alcohol-related stimuli in both groups could be partly explained by the higher luminance of the alcohol-related stimuli compared to flower stimuli. Moreover, while the size of the pictures was standardized, we did not control for the size of the main object within the alcohol-related and flower pictures, although bigger stimuli are known to be detected easier and faster (Hoffmann et al. 2021). Finally, the use of flower rather than non-alcoholic beverages as neutral stimuli, although justified by physical aspects, did not allow for dissociating the alcohol-related and appetitive nature of alcoholic beverage pictures. Nevertheless, these potential effects should be found in all participants, and thus would not impact the target × group interactions we were interested in to detect the presence of an automatic alcohol-related AB specific to binge drinkers.

Conclusion

The present study demonstrates that, while binge drinkers present a preserved early salience processing (as confirmed by the replication of the effects previously established for faces), the AB towards alcohol-related stimuli in binge drinking is not characterized by an automatic capture of attention but rather appears on later and more controlled attentional processing stages.

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Data Availability Raw data of the present study are available upon request.

Declarations

Conflict of interest The authors declare no competing interests.

References

Albery IP (2015) Testing a frequency of exposure hypothesis in attentional bias for alcohol-related stimuli amongst social drinkers. Addictive Behaviors Reports, 5

Almeida-Antunes N, Antón-Toro L, Crego A, Rodrigues R, Sampaio A, López-Caneda E (2022) « It's a beer! »: brain functional hyperconnectivity during processing of alcohol-related images in young binge drinkers. Addiction Biology, 27(2). https://doi.org/10.1111/adb.13152

Ataya AF, Adams S, Mullings E, Cooper RM, Attwood AS, Munafò MR (2012) Internal reliability of measures of substance-related cognitive bias. Drug Alcohol Depend 121(1–2):148–151. https://doi.org/10.1016/j.drugalcdep.2011.08.023

Bechara A (2005) Decision making, impulse control and loss of willpower to resist drugs: a neurocognitive perspective. Nat Neurosci 8(11):1458–1463. https://doi.org/10.1038/nn1584

Beck AT, Steer RA, Brown GK (1998) Beck depression inventory manual, 2nd edn. Editions du Centre de Psychologie Appliquée, Paris

Blanco-Ramos J, Cadaveira F, Folgueira-Ares R, Corral M, Rodríguez Holguín S (2019) Electrophysiological correlates of an alcohol-cued go/nogo task: a dual-process approach to binge drinking in university students. Int J Environ Res Public Health 16(22):4550. https://doi.org/10.3390/ijerph16224550

Bollen Z, Field M, Billaux P, Maurage P (2022) Attentional bias in alcohol drinkers: a systematic review of its link with consumption variables. Neurosci Biobehav Rev 139:104703. https://doi.org/10.1016/j.neubiorev.2022.104703

Bollen Z, Masson N, Salvaggio S, D'Hondt F, Maurage P (2020) Craving is everything: an eye-tracking exploration of attentional bias in binge drinking. J Psychopharmacol, 026988112091313. https://doi.org/10.1177/0269881120913131

Brainard DH (1997) The psychophysics toolbox. Spat vis 10(4):433–436. https://doi.org/10.1163/156856897X00357

Bruchon-Schweitzer M, Paulhan I (1993) Adaptation francophone de l'inventaire d'anxiété Trait-Etat (Forme Y) de Spielberger. Editions du Centre de Psychologie Appliquée, Paris

Carbia C, López-Caneda E, Corral M, Cadaveira F (2018) A systematic review of neuropsychological studies involving young binge drinkers. Neurosci Biobehav Rev 90:332–349. https://doi.org/10.1016/j.neubiorev.2018.04.013

Christiansen P, Mansfield R, Duckworth J, Field M, Jones A (2015) Internal reliability of the alcohol-related visual probe task is increased by utilising personalised stimuli and eye-tracking. Drug Alcohol Depend 155:170–174. https://doi.org/10.1016/j.drugalcdep.2015.07.672

Crego A, Holguín SR, Parada M, Mota N, Corral M, Cadaveira F (2009) Binge drinking affects attentional and visual working memory processing in young university students. Alcoholism: Clin Exp Res, 33(11), 1870-1879. https://doi.org/10.1111/j.1530-0277.2009.01025.x

Crouzet SM, Kirchner H, Thorpe SJ (2010) Fast saccades toward faces: face detection in just 100 ms. J vis 10(16):1–17

DePalma FM, Ceballos N, Graham R (2017) Attentional blink to alcohol cues in binge drinkers versus non-binge drinkers. Addict Behav 73:67–73. https://doi.org/10.1016/j.addbeh.2017.04.020

Devillez H, Guyader N, Curran T, O'Reilly RC (2020) The bimodality of saccade duration during the exploration of visual scenes. Vis Cogn 28(9):484–512. https://doi.org/10.1080/13506285.2020.1830325

Elton A, Faulkner ML, Robinson DL, Boettiger CA (2021) Acute depletion of dopamine precursors in the human brain: effects on functional connectivity and alcohol attentional bias. Neuropsychopharmacology. https://doi.org/10.1038/s41386-021-00993-9

Field M, Hogarth L, Bleasdale D, Wright P, Fernie G, Christiansen P (2011) Alcohol expectancy moderates attentional bias for alcohol cues in light drinkers. Addiction 106(6):1097–1103. https://doi.org/10.1111/j.1360-0443.2011.03412.x

Field M, Mogg K, Mann B, Bennett GA, Bradley BP (2013) Attentional biases in abstinent alcoholics and their association with craving. Psychol Addict Behav 27(1):71–80. https://doi.org/10.1037/a0029626

Field M, Mogg K, Zetteler J, Bradley BP (2004) Attentional biases for alcohol cues in heavy and light social drinkers: the roles of initial orienting and maintained attention. Psychopharmacology 176(1):88–93. https://doi.org/10.1007/s00213-004-1855-1

Foulsham T, Gray A, Nasiopoulos E, Kingstone A (2013) Leftward biases in picture scanning and line bisection: a gaze-contingent window study. Vision Res 78:14–25. https://doi.org/10.1016/j.visres.2012.12.001

Franken IHA (2003) Drug craving and addiction: integrating psychological and neuropsychopharmacological approaches. Prog Neuropsychopharmacol Biol Psychiatry 27(4):563–579. https://doi.org/10.1016/S0278-5846(03)00081-2

Gache P, Michaud P, Landry U, Accietto C, Arfaoui S, Wenger O, Daeppen J-B (2005) The alcohol use disorders identification test (AUDIT) as a screening tool for excessive drinking in primary care: reliability and validity of a French version. Alcoholism: Clin Exp Res, 29(11), 2001-2007. https://doi.org/10.1097/01.alc.0000187034.58955.64

Gladwin TE, ter Mors-Schulte MHJ, Ridderinkhof KR, Wiers RW (2013) Medial parietal cortex activation related to attention control involving alcohol cues. Front Psych, 4. https://doi.org/10.3389/fpsyt.2013.00174

Guyader N, Chauvin A, Boucart M, Peyrin C (2017) Do low spatial frequencies explain the extremely fast saccades towards human faces? Vision Res 133:100–111. https://doi.org/10.1016/j.visres.2016.12.019

Hallgren K, McCrady B (2013) Interference in the alcohol Stroop task with college student binge drinkers. J Behav Health 2(2):112. https://doi.org/10.5455/jbh.20130224082728

Heitmann J, Jonker NC, Ostafin BD, de Jong PJ (2020) Attentional bias for alcohol cues in visual search-Increased engagement, difficulty to disengage or both? PloS One, 15(1), e0228272. https://doi.org/10.1371/journal.pone.0228272

Hoffmann A, Büsel C, Ritter M, Sachse P (2021) Do emotional stimuli interfere with response inhibition? Evidence from the antisaccade paradigm. Cogn Emot 35(8):1626–1633. https://doi.org/10.1080/02699931.2021.1979475

Kauffmann L, Khazaz S, Peyrin C, Guyader N (2021) Isolated face features are sufficient to elicit ultra-rapid and involuntary orienting responses toward faces. J vis 21(2):4. https://doi.org/10.1167/jov.21.2.4

Kauffmann L, Peyrin C, Chauvin A, Entzmann L, Breuil C, Guyader N (2019) Face perception influences the programming of eye movements. Sci Rep 9(1):560. https://doi.org/10.1038/s41598-018-36510-0

King AC, Byars JA (2004) Alcohol-induced performance impairment in heavy episodic and light social drinkers. J Stud Alcohol, 65(1), 27-36. https://doi.org/10.15288/jsa.2004.65.27

Kirchner H, Thorpe SJ (2006) Ultra-rapid object detection with saccadic eye movements: visual processing speed revisited. Vision Res 46:1762–1776

Langbridge JE, Jones RD, Canales JJ (2019) A neurophysiological and behavioral assessment of interventions targeting attention bias and sense of control in binge drinking. Front Hum Neurosci 12:538. https://doi.org/10.3389/fnhum.2018.00538

Lannoy S, Baggio S, Heeren A, Dormal V, Maurage P, Billieux J (2021) What is binge drinking? Insights from a network perspective. Add Behav 117:106848. https://doi.org/10.1016/j.addbeh.2021.106848

Lannoy S, Billieux J, Dormal V, Maurage P (2019) Behavioral and cerebral impairments associated with binge drinking in youth: a critical review. Psychologica Belgica 59(1):116–155. https://doi.org/10.5334/pb.476

Lannoy S, Dormal V, Billieux J, Brion M, D'Hondt F, Maurage P (2020) A dual-process exploration of binge drinking: evidence through behavioral and electrophysiological findings. Add Biol, 25(2). https://doi.org/10.1111/adb.12685

Lees B, Mewton L, Stapinski LA, Squeglia LM, Rae CD, Teesson M (2019) Neurobiological and cognitive profile of young binge drinkers: a systematic review and meta-analysis. Neuropsychol Rev 29(3):357–385. https://doi.org/10.1007/s11065-019-09411-w

Lopez-Caneda E, Cadaveira F, Crego A, Doallo S, Corral M, Gomez-Suarez A, Rodriguez Holguin S (2013) Effects of a persistent binge drinking pattern of alcohol consumption in young people: a follow-up study using event-related potentials. Alcohol Alcohol 48(4):464–471. https://doi.org/10.1093/alcalc/agt046

López-Caneda E, Rodríguez Holguín S, Cadaveira F, Corral M, Doallo S (2014) Impact of alcohol use on inhibitory control (and vice versa) during adolescence and young adulthood : a review. Alcohol Alcohol 49(2):173–181. https://doi.org/10.1093/alcalc/agt168

Maurage P, Lannoy S, Mange J, Grynberg D, Beaunieux H, Banovic I, Gierski F, Naassila M (2020) What we talk about when we talk about binge drinking: towards an integrated conceptualization and evaluation. Alcohol Alcohol 55(5):468–479. https://doi.org/10.1093/alcalc/agaa041

McAteer, Curran D, Hanna D (2015) Alcohol attention bias in adolescent social drinkers: an eye tracking study. Psychopharmacology, 232(17), 3183-3191https://doi.org/10.1007/s00213-015-3969-z

McAteer, Hanna D, Curran D (2018) Age-related differences in alcohol attention bias: a cross-sectional study. Psychopharmacology, 235(8), 2387-2393 https://doi.org/10.1007/s00213-018-4935-3

Monem RG, Fillmore MT (2017) Measuring heightened attention to alcohol in a naturalistic setting: a validation study. Exp Clin Psychopharmacol 25(6):496–502. https://doi.org/10.1037/pha0000157

Müller-Oehring EM, Le Berre A-P, Serventi M, Kalon E, Haas AL, Padula CB, Schulte T (2019) Brain activation to cannabis- and alcohol-related words in alcohol use disorder. Psych Res. Neuroimaging 294:111005. https://doi.org/10.1016/j.pscychresns.2019.111005

Pelli DG (1997) The VideoToolbox software for visual psychophysics: transforming numbers into movies. Spat vis 10(4):437–442. https://doi.org/10.1163/156856897X00366

Petit G, Kornreich C, Noël X, Verbanck P, Campanella S (2012) Alcohol-related context modulates performance of social drinkers in a visual go/no-go task: a preliminary assessment of event-related potentials. PLoS ONE 7(5):e37466. https://doi.org/10.1371/journal.pone.0037466

Popa L, Selejan O, Scott A, Mureşanu DF, Balea M, Rafila A (2015) Reading beyond the glance: eye tracking in neurosciences. Neurol Sci 36(5):683–688. https://doi.org/10.1007/s10072-015-2076-6

Ryerson NC, Neal LB, Gable PA (2017) Attenuating the alcohol allure: attentional broadening reduces rapid motivational response to alcohol pictures. Psychopharmacology 234(8):1247–1254. https://doi.org/10.1007/s00213-017-4557-1

Robinson TE, Berridge KC (1993) The neural basis of drug craving: an incentive-sensitization theory of addiction. Brain Res Rev 18(3):247–291. https://doi.org/10.1016/0165-0173(93)90013-P

Saunders JB, Aasland OG, Babor TF, De La Fuente JR, Grant M (1993) Development of the alcohol use disorders identification test (AUDIT): WHO collaborative project on early detection of persons with harmful alcohol consumption-II. Addiction 88(6):791–804. https://doi.org/10.1111/j.1360-0443.1993.tb02093.x

Sharbanee JM, Stritzke WGK, Wiers RW, MacLeod C (2013) Alcohol-related biases in selective attention and action tendency make distinct contributions to dysregulated drinking behaviour: alcohol-biases in selective attention and action tendency. Addiction 108(10):1758–1766. https://doi.org/10.1111/add.12256

Theeuwes J, Van der Stigchel S (2006) Faces capture attention: evidence from inhibition of return. Vis Cogn 13(6):657–665. https://doi.org/10.1080/13506280500410949

Tibboel H, De Houwer J, Field M (2010) Reduced attentional blink for alcohol-related stimuli in heavy social drinkers. J Psychopharmacol 24(9):1349–1356. https://doi.org/10.1177/0269881109106977

Townshend JM, Duka T (2002) Patterns of alcohol drinking in a population of young social drinkers: a comparison of questionnaire and diary measures. Alcohol Alcohol 37:187–192

Townshend JM, Duka T (2005) Binge drinking, cognitive performance and mood in a population of young social drinkers. Alcoholism: Clin Exp Res, 29(3), 317-325. https://doi.org/10.1097/01.ALC.0000156453.05028.F5

Townshend JM, Duka T (2007) Avoidance of alcohol-related stimuli in alcohol-dependent inpatients. Alcoholism: Clin Exp Res, 31(8), 1349-1357. https://doi.org/10.1111/j.1530-0277.2007.00429.x

Wiers CE, Gladwin TE, Ludwig VU, Gröpper S, Stuke H, Gawron CK, Wiers RW, Walter H, Bermpohl F (2016) Comparing three cognitive biases for alcohol cues in alcohol dependence. Alcohol and Alcoholismhttps://doi.org/10.1093/alcalc/agw063

Wiers RW, Bartholow BD, van den Wildenberg E, Thush C, Engels RCME, Sher KJ, Grenard J, Ames SL, Stacy AW (2007) Automatic and controlled processes and the development of addictive behaviors in adolescents: a review and a model. Pharmacol Biochem Behav 86(2):263–283. https://doi.org/10.1016/j.pbb.2006.09.021