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Assessing attentional bias for alcohol-related cues using eye tracking in a virtual reality environment

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Several experimental paradigms were developed to measure attentional biases towards alcohol-related cues. However, most of them are based on reaction times to two-dimensional stimuli displayed on a computer screen, such that their ecological validity has been questioned. To address this, we integrated an eye tracking system into a virtual reality headset (ET-VR) and measured attentional biases in a subclinical population of alcohol users. In this exploratory study, forty social drinkers were recruited and immersed in a virtual bar including alcohol-related stimuli. Attentional focus was assessed using dwell time and number of fixations for these alcohol-related stimuli as well as for neutral stimuli unrelated to alcohol consumption. The results show that the number of fixations and, to a lesser extent, the dwell time for alcohol-related cues were positively correlated with the drinking motivation of the participants. In contrast, no significant correlation was found for neutral stimuli. In conclusion, the present study shows that alcohol-induced attentional biases can be studied using an ET-VR device in a subclinical population of alcohol users.

KEYWORDS

virtual reality, eye tracking, cue exposure, craving, immersion

1 Introduction

Alcohol is a psychoactive substance that has been widely consumed in many cultures for centuries. In 2016, the harmful use of alcohol resulted in some 3 million deaths worldwide (5.3% of global deaths) (World Health Organization, 2018). Beyond the physical repercussions, alcohol use disorder is associated with major socioeconomic and mental health consequences (Hasin et al., 2007; Grant et al., 2015).

Current dual process models of addiction emphasize the relevance of implicit mechanisms, such as attentional bias for substance-related cues, in guiding addictive behaviour and contributing to the development and persistence of drug and alcohol use disorders (Fadardi and Cox, 2006; Wiers et al., 2007; Field and Cox, 2008). Theoretically, the emergence of attentional bias is explained by the incentive sensitization theory of addiction (Robinson and Berridge, 1993; Berridge and Robinson, 2016), which posits that repeated drinking occasions cause alcohol-related stimuli to acquire incentive-motivational properties. These cues can lead to an increase in subjective craving and an implicit shift in the allocation of attentional resources, such that the substance-relevant cues become the focus of attention. The bidirectional relationship between craving and attentional biases can lead to substance-seeking behaviour and is believed to be a major determinant in the development of addiction and predicts relapse processes (Cox et al., 2002; Field and Cox, 2008). As with craving, the strength of attentional bias towards alcohol-related stimuli appears to be proportional to individual differences in consumption (Field et al., 2014).

Most studies investigate attentional biases through reaction time (RT) recorded in attentional tasks, such as the addiction Stroop task (Cox et al., 2006), the visual probe task (Ehrman et al., 2002; van Hemel-Ruiter et al., 2016), adapted versions of the Go/No-go task (Kreusch et al., 2013) and of the Stop-Signal task (Kreusch et al., 2017), the flicker change blindness paradigm (Jones et al., 2002), the attentional cueing (Garland et al., 2012), the rapid serial visual presentation (Brown et al., 2018), or the cued target detection task (Abroms and Fillmore, 2004). Together, these studies conclude that RT-based attentional biases are more pronounced in patients with alcohol use disorder than in control participants (for a review, Field et al., 2009). Similarly, some authors show more pronounced attentional biases in heavy relative to occasional drinking individuals (Townshend and Duka, 2001; Bruce and Jones, 2004; Field et al., 2007; Fadardi and Cox, 2009; White et al., 2014; Manchery et al., 2017). However, the reported results are usually of small sizes and sometimes inconsistent, particularly in social drinkers (Hallgren and McCrady, 2013; Groefsema et al., 2016). Criticisms have been made about these indirect measures of attentional biases (for a critical review see Christiansen et al., 2015a; Field et al., 2016; Rodebaugh et al., 2016). The poor complexity and ecological validity of the experimental paradigms are believed to reduce the size of the observed effects. The interpretation of attentional bias indexes (i.e., generally a ratio between the average RTs for non-alcohol- and alcohol-related items) is complex and unclear. The psychometric properties of these tests are often poor due to the contamination of the measures by cognitive strategies that participants may employ in an attempt to suppress attentional bias, and by the motor aspects of behavioural outputs required to perform the tasks (motor preparation and response execution). Finally, RT-based attentional bias measures most often ignore the dynamic nature of attentional processes.

To address the methodological limitations of RT-based attentional bias paradigms, some direct measures of attention using eye tracking techniques were considered. These methods, which are based on the detection of gaze direction to infer attentional processes, have a high temporal resolution. In some cases, eye tracking techniques were combined with another RT-based attentional task. These studies found that gaze measures were more robust than RTs (Miller and Fillmore, 2010; Christiansen et al., 2015a; van Duijvenbode et al., 2017; Bollen et al., 2020). Other studies used eye tracking without a concurrent RT-based attentional task. Typically, alcoholic vs non-alcoholic stimuli are presented side by side on a computer screen while initial fixation and total dwell time (i.e., overall fixation time on each area of interest) per stimulus type are measured. These studies reported that dwell time on alcoholic stimuli was associated with individual levels of alcohol consumption (McAteer et al., 2015; McAteer et al., 2018) and positive alcohol expectancies (McAteer et al., 2015). In summary, these studies indicate that attentional biases associated with alcohol consumption might be better understood in terms of dynamic attention mechanisms investigated with eye tracking techniques.

To better approach the real-life complexity, some researchers used more complex pictures, such as visual scenes with and without alcohol-related cues. They showed that the number of saccades (rapid eye movements that shift the centre of gaze from one part of the visual field to another) in and out of the alcohol-related areas was positively correlated with alcohol consumption. Furthermore, heavy drinking individuals' attention was consistently drawn back to alcohol-related objects once they were first fixated and when attention was reinforced by other cognitive demands, such as the memorization of complex images. Under low cognitive demand (i.e., looking at the pictures as if you were looking at your friends' pictures on Facebook), eye movements towards alcohol-related objects were not correlated with alcohol consumption. Therefore, it seems necessary for participants to be fully engaged in a cognitive task for these more automatic mechanisms to emerge. The fixation time and the speed of the first fixation in alcohol-related regions, however, did not differentiate heavy drinking individuals from occasional drinkers (Roy-Charland et al., 2017). In a similar vein, Pennington et al. (2019) developed a "conjunction search eye tracking task" where participants detected an alcoholic or non-alcoholic target picture in a set of matched and unmatched distractors. Their results suggest that social drinking individuals were faster at detecting both alcoholic and non-alcoholic appetitive targets compared to non-appetitive targets. However, there was no significant difference in search performance between alcoholic and non-alcoholic appetitive targets. In a second study using the same paradigm, Soleymani et al. (2020) found that participants with higher craving scores and higher alcohol use disorder symptoms dwelt longer on alcohol stimuli, and were more likely to first fixate on alcohol-related cues. Furthermore, stronger craving was associated with shorter latencies of first alcohol fixations.

However, two-dimensional images of alcohol-related stimuli on a computer screen cannot adequately reflect the complexity of

TABLE 1 Demographic data, psychological characteristics and sense of presence.

	N (%)	Mean (SD)	Min—max
Age		26.2 (3.9)	19–34
Gender (M/F)	20/20		
Education (years)		14.7 (2.3)	10–20
AUDIT score		6.8 (4.7)	1–23
OCDS		1.0 (1.6)	0–8
Obsessive thoughts of drinking			
Compulsive drinking		3.5 (2.7)	0–10
UPPS-P		9.4 (1.5)	7–13
Negative urgency			
Positive urgency		11.8 (2.3)	7–16
Lack of premeditation		7.8 (2.7)	4–16
Lack of perseverance		8.1 (2.6)	4–15
Sensation seeking		9.8 (2.8)	4–15
CES-D		19.4 (14.5)	1–50
Immersive Tendencies (ITQ)		23.4 (4.3)	16–32
Focus			
Involvement		19.3 (6.9)	5–31
Emotion		16.5 (4.6)	6–26
Game		8.9 (4.5)	3–17
Presence (Gatineau)		43.2 (17.7)	1.25–67.5

Note. SD, standard deviation; AUDIT, alcohol use disorders identification test; OCDS, obsessive compulsive drinking scale; UPPS-P, impulsive behaviour scale; CES-D, center for epidemiologic studies-depression; ITQ, immersive tendencies questionnaire.

real-life substance use situations (Hertel and Mathews, 2011). Two major approaches are therefore being explored to increase the ecological validity of attentional bias assessment. First, the use of wearable eyeglasses allows for the measure of alcohol attentional biases in more naturalistic settings, for example where bottles of alcoholic beverages are positioned alongside bottles of soda (Monem and Fillmore, 2017). The results of such studies indicate that relatively long fixations on alcoholic beverages compared to sodas were associated with higher reported alcohol consumption during the past 90 days. Secondly, the rise of new technologies, particularly virtual reality (VR), allows immersing participants in virtual, controlled, and near-reality environments that provide a new ecological framework to study complex behaviours (Parsons, 2015). Several studies showed that it is possible to elicit craving for various addictive substances after immersion in a VR environment (for a review, see Pericot-Valverde et al., 2016; Bordnick and Washburn, 2019; Segawa et al., 2020). So far, only a few studies have used VR to induce craving together with an independent assessment of attentional biases with an eye-tracking technique, but attentional biases were measured outside of the VR environment (Choi and Lee, 2015; Ghiţă et al., 2021).

In the field of attentional bias assessment, it is easy to see the benefits that could be drawn from the combination of VR and eye tracking techniques. This would allow recording attentional biases in three-dimensional virtual environments very close to reality, thereby addressing the methodological limitations of current RT-based and two-dimensional eye tracking paradigms. However, this remains limited by the technical challenge of integrating eye tracking and VR techniques. The purpose of the present study was to assess attentional biases for alcohol-related cues using an eye tracking system into a virtual reality helmet (ET-VR). To do this, we proceeded in two stages. First, an expert team of engineers, VR developers and psychologists developed the ET-VR technology. Second, we tested whether it was possible to assess attentional biases for alcohol-related cues using this ET-VR device. A pioneer study first considered head-pointing angle as a measure of the subjective viewpoint and derived visually explored regions of interest (ROIs) to measure sexual preferences (Renaud et al., 2002). More recently, studies exploited ET-VR to explore attentional biases in eating disorder (Porras-Garcia et al., 2019) and social anxiety (Mühlberger et al., 2008; Reichenberger et al., 2020). In the present exploratory study, participants were immersed in an alcohol-related environment in which some environmental stimuli were tagged as alcohol-related cues. Attentional focus was assessed using the dwell time and the number of fixations for these alcohol-related cues as well as for predefined "neutral" cues unrelated to alcohol consumption. In order to confirm the validity of the device, we expected to find positive correlations between these measures of attentional focus for alcohol-related cues and the participants' levels of alcohol craving and consumption (Roy-Charland et al., 2017; Soleymani et al., 2020), whereas no such relationship would be observed for neutral cues. Alcohol craving and consumption were selected as criteria to test for concurrent validity because they are predictive of alcohol-related attentional biases. In the second part of the study, we measured the internal consistency of the dwell time and the number of fixations for the predefined alcohol-related cues. Finally, we calculated a composite alcohol-related attentional bias score and tested whether it correlates with the sense of presence (Simon et al., 2020) and other variables that might be expected to relate to alcohol use disorders in order to test for concurrent and divergent validity. More precisely, we tested the correlation between the composite attention bias score and impulsivity (Smith and Anderson, 2001; Field and Cox, 2008; Coskunpinar and Cyders, 2013), depression (McHugh and Weiss, 2019), as well as alcohol consumption and craving (Field and Cox, 2008).

2 Methods

2.1 Participants

Fifty alcohol users (Table 1), between 18 and 35 years old, were recruited in the general population through an online screening questionnaire. They did not report having colour blindness, neurological, developmental or psychiatric problems and reported being free from drugs that could affect cognitive functioning. They reported having good sight without glasses. Participants were excluded if they used cannabis regularly or other illicit substances more than twice in the last 2 months. They had neither been diagnosed as presenting alcohol use disorder nor been involved in an alcohol-related treatment. Participants with severe motion sickness (i.e., reporting being consistently nauseous and/or vomiting in at least two transport situations) were also excluded based on a modified version of the motion sickness susceptibility questionnaire (Golding, 1998). This questionnaire was used to determine sensitivity to kinetosis, which is moderately correlated with a general tendency towards cybersickness (Kim et al., 2005).

A total of ten participants were excluded after the laboratory visit either because they did not report drinking alcohol at least once a month (their Alcohol Use Disorders Identification Test (AUDIT) (Saunders et al., 1993) score was equal to 0, $n = 4$), because of technical problems ($n = 3$), inadequate calibration of the eye tracking ($n= 2$) or nystagmus ($n = 1$). The total number of participants included in the study was forty.

2.2 Questionnaires

2.2.1 Alcohol consumption

The French version (Gache et al., 2005) of the *Alcohol Use Disorders Identification Test* [AUDIT (Saunders et al., 1993)] includes 10 multiple-choice items measuring alcohol consumption, alcohol dependence and alcohol-related problems. High scores reflect a high probability of harmful alcohol use, with a maximum score of 40. Scores from 1 to 7 suggest low risk drinking; scores of 8–15 indicate alcohol use in excess, and scores of 16 and above imply harmful and hazardous drinking (Babor et al., 2001).

2.2.2 Tonic alcohol craving

The French version (Ansseau et al., 2000) of the Obsessive Compulsive Drinking Scale (Anton et al., 1995) is a 14-item, self-administered questionnaire assessing obsessive thoughts of drinking and compulsive drinking during the last 7 days in two subscales. Scores on each subscale range from 0 to 20. Higher scores indicate stronger obsessions and compulsions towards alcohol.

2.2.3 Substance use

This questionnaire assesses the use frequency of cannabis, cocaine, ecstasy, hallucinogens, amphetamines, opiates, and volatile solvents in the past 2 months on a 4-point likert scale ("never"—"once/twice"—"more than twice"—"regular use").

2.2.4 Impulsivity

The short version of the French Impulsive Behaviour Scale [UPPS-P (Billieux et al., 2012)] is a 20-item scale assessing impulsivity on five dimensions through a 4-point likert scale (1 = "strongly disagree" to 4 = "strongly agree"). The dimensions are positive urgency (i.e., to act rashly under conditions of positive affect), negative urgency (i.e., to act rashly under conditions of negative affect), lack of premeditation (i.e., the inability to remain focused on a task), and sensation seeking (i.e., the tendency and openness to enjoy exciting or dangerous activities).

2.2.5 Depressed mood

Severity of depressive symptoms experienced during the last 7 days was assessed with the French version (Fuhrer and Rouillon, 1989) of the Center for Epidemiologic Studies—Depression [CES-D; (Radloff, 1977)]. The CES-D consists of 20 items rated on a 4-point likert scale (0 = "never" to 3 = "frequently, all the time"). The total score ranges from 0 to 60 with higher scores indicating higher symptom severity.

2.2.6 Motion sickness

The Motion Sickness Susceptibility Questionnaire [MSSQ; (Golding, 1998)] assesses motion sickness experienced during various transportation-related activities and other activities. It contains 9 categories of possible experiences that elicit motion sickness (e.g., cars, buses, swings, funfairs). Each item is rated on a 5-point scale (1 = "never" to 5 = "always").

2.2.7 Immersive tendencies in media

The French version (Robillard et al., 2002) of the Immersive Tendencies Questionnaire [ITQ; (Witmer and Singer, 1998)] assesses one's tendency to shut out external distractions in order to focus on different tasks in daily life. It contains 18 items where participants rate their level of agreement on a 7-point scale. Four dimensions are derived: focus (i.e., the tendency to maintain focus on current activities), involvement (i.e., the tendency to become involved in activities), emotion (i.e., the ease of feeling intense emotions evoked by the activity), and game (i.e., the tendency to play video games).

2.2.8 The sense of presence

The Gatineau Presence Questionnaire (Laforest et al., 2016) measures the feeling of presence experienced in a virtual environment. Through 4 items rated on a scale of 0–100, this questionnaire assessed 1) the sense of being there, 2) appraising the experience as being real, 3) awareness of the virtual environment as being artificial, and 4) the feeling of being in the physical office instead of the virtual environment. The last two items are scored in reverse and an average score is computed.

2.3 Virtual reality and eye tracking system

2.3.1 Apparatus

We used an HTC VIVE VR headset in which we integrated eye tracking devices from Pupil Labs. The Pupil Labs code is open

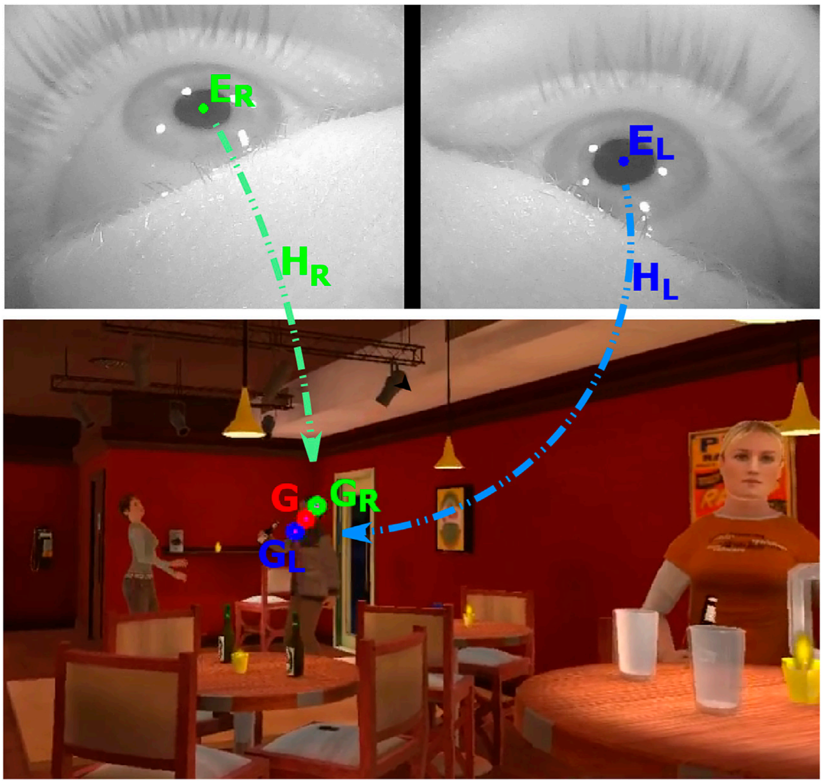

FIGURE 1
The center of the left pupil (EL) and right pupil (ER) are mapped to two points (GL,GR) on a plane in front of the subject via the homography matrices HL and HR. The gaze point (G) is computed as the mean of GL and GR.

source and can be adapted to various VR headsets. Specifically, this device consisted of two rings fixed in the headset, one for each eye, with a camera capturing eye images at the bottom, and infrared LED placed around the ring to illuminate the eye.

2.3.2 Live gaze tracking

Once the subject was equipped with the VR headset, the experimenter adjusted the parameters of the pupil detector: minimal and maximal value for the pupil size and coarse maximal value for the pupil luminosity. The virtual simulation started with the calibration in which the participant fixated white dots appearing around a circle on a plane P. During this time, the position of the pupils and their corresponding points on the plane P were gathered and communicated to the VR engine Unity *via* a communication library called ZeroMQ. Those correspondences were used at the end of the calibration to compute two homography matrices (one for each eye) [H_L, H_R] that mapped pupil positions [E_L, E_R] (pixel of the camera image) to gaze coordinates [G_L, G_R] (point on the plane P in the virtual world). At each frame, the pupil positions [E_L, E_R] were retrieved from pupil labs software through a ZMQ connection, and converted to gaze coordinates [G_L, G_R] on the plane P *via* the homography matrices [H_L, H_R]. The gaze point G was obtained by computing the mean between G_L and G_R (Figure 1).

2.3.3 Regions of interest and gaze interaction

During the experiment, participants were immersed in a virtual bar where they heard background music, saw people dancing and/or drinking beer. It included the following spaces: a counter, tables and a dance floor. The experimenter could bring out two light markers on the ground independently of each other (Figure 2). One was near the front door while the other was near the dance floor. These light markers allowed the standardization of participants' positions in the environment during the immersion. This environment was originally developed by the Université du Québec en Outaouais' Cyberpsychology lab (Loranger and Bouchard, 2017) and adapted for the alcohol-related research. In a previous study, this environment was shown to elicit alcohol craving, especially in heavy drinking individuals (Simon et al., 2020).

Several items in the environment were considered as ROI. Some of these were associated with alcohol consumption while others were more neutral and used as controls (Figure 2 and Table 2). Alcohol-related cues were selected based on a pilot

FIGURE 2
Screenshot of the virtual environment and light markers on the ground.

TABLE 2 List of alcohol-related and neutral stimuli.

Alcohol-related stimuli	Neutral stimuli
The bartender at the bar, chatting with a customer	3 soft drink cans
7 bottles/groups of bottles of alcohol	10 chairs
3 clusters of empty glasses of alcohol	29 lights: 7 spots on the dance floor and 22 lights in the bar
A cash register	2 televisions
7 advertisements promoting alcoholic drinks	The bar exit door

study in which ten psychology students were asked to identify cues that they believed are associated with alcohol. These ROI were recorded and labelled using colliders. A collider is an invisible volume, usually surrounding a virtual item, which allows the virtual environment to react to an interaction with the item. At each frame, an invisible ray was cast from the centre of the head of the user's avatar through the point G. The ray stopped when it reached a collider or a distance DMAX. If the ray hit a collider tagging an item in a tracked category, a timer started. It ended when the ray leaves the item and a record was then logged. Else, the ray stopped after a distance DMAX to avoid hitting and recording irrelevant items in the background. Since the whole process was live, no data filtering was done during acquisition.

A fixation was defined as holding one's gaze on a single ROI over a period of at least 100 ms. A threshold of 100 ms therefore discriminated fixations from other oculomotor activity and was consistent with current physiological and visuo-cognitive models (Manor and Gordon, 2003). For each ROI, a dwell time (i.e., overall fixation time for each ROI) and a number of fixations (i.e., the number of times a fixation was made in this ROI) were calculated. A sum for the duration and the number of fixations was then calculated for all items in the same category (bottle of alcohol, glasses, etc.) (Porras-Garcia et al., 2019).

2.4 Procedure

The study was approved by the local ethics committee of the Faculty of Psychology, Speech Therapy, and Educational Science of the University of Liège and was conducted following the ethical

TABLE 3 Means, standard deviations, minimums, and maximums for eye tracking data for alcohol-related and neutral stimuli.

	Area of interest	Mean (SD)	Min—max
Total duration of fixations	Bartender	4267 (2334)	1273–13271
	Alcohol bottles	6689 (2987)	1594–16682
	Glasses	6215 (2317)	1321–10996
	Cash register	6880 (2930)	1415–13845
	Advertisements	18889 (8089)	4687–38202
	Cans	1011 (1008)	0–3603
	Bar exit door	7263 (5481)	1416–33104
	Chairs	10128 (8287)	1317–43653
	Lights	12120 (14674)	3226–99424
	TV	13653 (11638)	244–58603
Number of fixations	Bartender	11.35 (4.97)	3–31
	Alcohol bottles	22.13 (6.76)	7–35
	Glasses	17.33 (5.43)	8–29
	Cash register	13.63 (5.23)	5–26
	Advertisements	42.55 (14.80)	15–81
	Cans	3.42 (3.04)	0–13
	Bar exit door	17.38 (8.44)	5–46
	Chairs	32.60 (18.17)	7–100
	Lights	35.78 (13.42)	9–63
	TV	24.03 (11.41)	2–64

Note. SD, standard deviation; total duration is expressed in ms.

standards as described in the Declaration of Rickham (1964). It involved two phases, including an online survey and a face-to-face meeting. During the online survey phase, and after providing an initial online informed consent, participants completed the sociodemographic items (age, gender, level of education, and items evaluating neurological, developmental or psychiatric problems), the MSSQ, the AUDIT, drug consumption, the CES-D, the QPI, and the UPPS-P. Thereafter, participants who met the inclusion criteria were contacted to participate in the second phase on the campus of the University, which took place during the afternoon or evening between 10 February 2021 and 12 July 2021. After providing a second-written informed consent, participants were immersed in VR. After the calibration stage, which could be repeated as needed, they were immersed into a virtual street and instructed to enter a building (the bar) and position themselves on a light marker on the ground. They had 2 minutes to soak up the atmosphere and visually explore the environment. After this, a new calibration took place to maximize the accuracy of the measurement. The instructions given were similar except for the positioning of the light marker, which was different. The total immersion time for which attentional biases were measured was 4 min. After the immersion, participants were asked to rate their sense of presence, and cybersickness during the immersion, as well as completing the OCDS. After the debriefing, participants signed a final consent form, this time indicating the real purpose of the experiment.

2.5 Statistical analyses

Positive correlations were expected between measures of alcohol consumption (AUDIT score) and craving (OCDS subscales) and were computed by Kendall's correlations. In an exploratory purpose, bilateral Kendall's correlations were also computed to test the relationship between AUDIT score or OCDS subscales score and the dwell time and number of fixations for each group of ROI. Non-parametric correlations were chosen to account for the non-normal distributions of the measures.

To estimate the internal consistency of the attentional bias measures, we computed McDonald's omega for the dwell time and number of fixations of alcohol-related stimuli (bartender, alcohol bottles, glasses, cash register and advertisement). McDonald's omega is a reliability coefficient for which values of 0.70 or higher are considered as acceptable (Revelle and Zinbarg, 2008).

Finally, we calculated two attentional bias scores, one based on the total number of fixations and the other for the dwell time on predefined alcohol-related items. To do this, we summed the total number of fixations or the dwell time for all alcohol-related ROIs (except for bottles). The attentional bias score was tested for his correlation with AUDIT, OCDS subscales, impulsivity, depressive symptomatology, and sense of presence scores. Bilateral Kendall's correlations were chosen for the first two and bilateral Pearson's correlations for the last three depending upon the compliance of the measures with the normal condition

TABLE 4 Bilateral Kendall's correlations between OCDS, AUDIT and dwell time.

		Obsessive thoughts	Compulsive drinking	AUDIT
Predefined alcohol-related items	Bartender	**0.48*** **	**0.30** **	0.19
	Alcohol bottles	0.24	0.19	−0.035
	Alcohol glasses	**0.38** **	**0.32** **	**0.32** **
	Cash register	0.14	0.22	0.11
	Advertising	0.18	0.08	0.14
Predefined neutral items	Alcohol-free drink cans	0.03	0.01	0.000
	Bar exit door	−0.14	−0.12	**−0.32** **
	Chairs	−0.08	−0.06	−0.13
	Lights	0.11	−0.07	0.01
	TV	0.12	0.058	0.08

Note. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
Values in bold correspond to statistics below the significance level.

assumption. Because of the exploratory and inductive nature of the present study, stricter statistical significance thresholds were not used to correct for multiple correlation tests.

3 Results

Means, standard deviations, minimum and maximum values for each group of ROI are shown in Table 3. On average, the overall fixation time for all preselected cues, both alcohol-related and neutral items, was 87 s out of a 4-min immersion session within the virtual environment (i.e., 36% of the duration of the experimental session).

Kendall's correlations revealed significant positive relationships between AUDIT score and the obsessive thoughts subscale (t_k = 0.39, p = 0.001), between AUDIT score and the compulsive drinking subscale (t_k = 0.52, $p < 0.001$), and between two subscales of the OCDS (t_k = 0.57, $p < 0.001$).

There was a significant positive correlation between OCDS subscales and dwell time associated with the bartender and the alcohol glasses. In addition, the AUDIT score correlated positively with the glasses and negatively with the bar exit door (Table 4). Furthermore, there were statistically significant positive correlations between OCDS subscales and the number of fixations related to the bartender, glasses, cash register and advertising. The AUDIT score showed a significant positive correlation with the glasses and a significant negative correlation with the bar exit door (Table 5).

Finally, two attentional bias composite scores were computed based on the number of total fixations for all alcohol-related ROIs (bartender, alcohol glasses, cash register, and advertising) or dwell time for these ROIs. Obsessive thoughts and compulsive drinking scale significantly correlated with both measures of attentional bias. Furthermore, the dimension of sensation seeking significantly correlated with the attentional bias related to dwell time (Table 6). McDonald's omega coefficients were computed to check the internal consistency of the attentional bias composite scores. When we considered all the ROI predefined as alcohol-related cues, the internal consistency was acceptable for the number of fixations (ω = 0.81) but not for dwell time (ω = 0.64). As there was no correlation between dwell time and the number of fixations for the alcohol bottles cues, the internal consistency was recalculated after removing these cues. This removal did not improve the internal consistency estimates. Again, the internal consistency was acceptable for the number of fixations (ω = 0.81) but not for dwell time (ω = 0.57). Additionally, the internal consistency for dwell time was not significantly improved by the removal of any of the other predefined ROIs.

4 Discussion

4.1 Summary of results

The purpose of this exploratory study was to explore attentional biases in an alcohol-related environment using an ET-VR device. The present study demonstrates that this is possible in a subclinical population of alcohol users. Indeed, our data suggest that the number of fixations and, to a lesser extent, the dwell time associated with predefined alcohol-related cues show significant positive correlations with alcohol drinking motivation (obsessive thoughts and compulsive drinking) in the past 7 days. In contrast, no such relationships were found for neutral stimuli, indicating the specificity of the observed correlations.

4.2 Correlations between attentional bias and tonic alcohol craving and consumption

The main purpose of the present study was to test whether alcohol-related attentional biases can be studied using an eye

TABLE 5 Bilateral Kendall's correlations between OCDS, AUDIT and the number of fixations.

		Obsessive thoughts	Compulsive drinking	AUDIT
Predefined alcohol-related items	Bartender	**0.40*****	**0.26***	0.14
	Alcohol bottles	0.12	0.14	−0.11
	Alcohol glasses	**0.44*****	**0.33****	**0.32****
	Cash register	**0.26***	**0.35****	0.19
	Advertising	**0.27***	**0.24***	0.14
Predefined neutral items	Alcohol-free drink cans	0.06	0.05	0.09
	Bar exit door	−0.05	−0.05	**−0.24***
	Chairs	−0.04	−0.02	−0.12
	Lights	0.13	−0.04	0.07
	TV	−0.04	−0.07	−0.01

Note. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
Values in bold correspond to statistics below the significance level.

TABLE 6 Kendall's and Pearson's correlations between attentional bias scores and alcohol craving, alcohol consumption, impulsivity, depressive symptomatology and sense of presence.

	Attentional bias	Attentional bias
	Fixation time	Number of fixations
Obsessive thoughts	**0.33****	**0.38****
Compulsive drinking	**0.24***	**0.33****
AUDIT	0.19	0.19
UPPS-P—Negative urgency	−0.01	−0.02
UPPS-P—Positive urgency	0.21	0.23
UPPS-P—Lack of premeditation	−0.008	0.06
UPPS-P—Lack of perseverance	0.11	0.22
UPPS-P—Sensation seeking	**0.32***	0.29
CES-D	−0.09	0.03
Sense of presence	0.15	0.168

Note. AUDIT, alcohol use disorders identification test; UPPS-P, impulsive behaviour scale; CES-D, Center for Epidemiologic Studies—Depression. *$p < 0.05$; **$p < 0.01$.

tracking technique implemented into a VR device. Significant correlations were obtained between the measures of attentional focus for alcohol-related cues and external measures of alcohol craving and consumption in the participants. Furthermore, the absence of significant correlations with neutral cues demonstrates the specificity of the measure to capture alcohol-related attentional biases. It is notable that the number of fixations appears to be a more robust measure of alcohol-related biases than dwell time in terms of both the correlation sizes and the internal consistency of the measures.

In some previous studies, the tonic component of craving was shown to be the most important determinant of attentional biases for alcohol-related cues (Hobson et al., 2013; Bollen et al., 2020; Soleymani et al., 2020), whereas lower correlations were found between attentional biases and self-reported levels of alcohol consumption (Heitmann et al., 2020; van Duijvenbode et al., 2017; Wilcockson et al., 2019) and alcohol use problems (Soleymani et al., 2020). In agreement with these previous results, stronger correlations were found in the present study between alcohol-related attentional biases and the OCDS, which assesses tonic craving during the last 7 days. In contrast, lower and sometimes non-significant correlations were observed between alcohol-related attentional biases and alcohol consumption and abuse as reported through the AUDIT. Furthermore, the present results also suggest that alcohol-related attentional biases more strongly correlate with the cognitive/ruminative dimension of OCDS.

In their meta-analysis, Field et al. (2009) found correlation sizes of r = 0.36 (95% CI = 0.26–0.46) between craving and attentional biases for all drugs combined when direct measures (such as eye tracking technic) are used. These authors also reported that the strength of the relationship was dependent upon the tested substance, with alcohol and tobacco producing lower correlations than other addictive substances. Furthermore, lower correlations are also expected in subclinical populations, in which drug- and alcohol-related attentional biases are less consistent, than in clinical populations with substance-related disorder (Hallgren and McCrady, 2013; Groefsema et al., 2016). As the present study assessed alcohol-related attentional biases in a non-clinical population of alcohol users, the sizes of the observed correlations were a bit stronger than what might have been expected based on such previous results, especially for the number of fixations. Although further studies will be required to confirm the present results, this might indicate the benefits of using VR to study the relationships between alcohol craving and attentional biases for alcohol-related cues.

The closer the cues present in a virtual environment are to those associated with the personal experience of alcohol consumption in the participants, the greater the correlation between attentional bias and tonic craving are expected. In the present study, we found stronger correlations with cues such as the bartender or alcohol glasses than with the advertisements or the cash register. Whereas statistically significant correlations were observed between tonic craving and most of the predefined alcohol-related cues, the items "alcohol bottles" constitute an unexpected exception. There are several possible explanations for this lack of significant correlation with the "alcohol bottles" cues. Firstly, these specific bottle stimuli did not show clear distinctive features of an alcohol brand, such that the participants might not have easily identified them as alcohol bottles. Secondly, these items were associated with relatively small colliders volumes compared to other cues in the virtual environment. Thirdly, two of these alcohol bottles were held by moving avatars in contrast to most of the other tagged cues that are stationary in the environment. Therefore, the precision of our visual tracking system might be insufficient to finely and accurately measure the visual fixations associated with these specific items. Whatever the reasons for this lack of correlation, these specific stimuli were removed from the attentional bias composite scores of the present exploratory study. Finally, an interesting negative correlation was observed between the AUDIT score and the time and number of fixations for the "bar exit door" cue. Although this correlation was not anticipated, it makes sense that high alcohol drinkers are less motivated to exit a bar than low alcohol drinkers. Further studies will be required first to replicate this unexpected correlation and then to confirm whether the bar exit door may be usefully incorporated as a negative item in an alcohol attentional bias composite score.

4.3 Correlations between attentional bias and impulsivity, depression and sense of presence

Several theoretical models suggest that impulsivity affects addictive behaviours partly by increasing attentional biases for drug-related cues (Smith and Anderson, 2001; Field and Cox, 2008). Accordingly, significant correlations are expected between measures of impulsivity and drug-related attentional biases. While previous studies reported statistically significant correlations between trait impulsivity and substance-related attentional biases, the sizes of these correlations are generally very small ($r = 0.10$; 95%IC of 0.01–0.19, see the meta-analysis of Coskunpinar and Cyders (2013). In the present study, correlations of similar magnitudes were observed between the composite score of alcohol attentional bias and impulsivity, although most of them failed to reach statistical significance. A notable exception is the statistically significant correlation with the sensation-seeking dimension of the UPPS-P. The literature about the relationship between the various sub-dimensions of impulsivity and alcohol-related behaviours remains conflicting. Previous studies did not always report a stronger relationship for sensation seeking relative to other dimensions of impulsivity and AUDIT scores (Thomsen et al., 2018; Flaudias et al., 2019a, 2019b) or alcohol craving (von Hammerstein et al., 2020). Very few studies investigated the correlations between the impulsivity dimensions and alcohol attentional biases (Coskunpinar and Cyders, 2013). The present results suggest that sensation seeking might have a special relationship with alcohol-related attentional biases that would require further investigation.

Alcohol abuse is often reported to be related to depression. For example, previous studies show positive correlations between depressive symptomatology and AUDIT (Khosravani et al., 2017; Thorberg et al., 2019; Bing-Canar et al., 2021) and with alcohol craving (Khosravani et al., 2017; Thorberg et al., 2019), although conflicting results have also been published (see for example Bing-Canar et al., 2021). Alcohol attentional biases were also suggested to be correlated with depressive symptomatology (Emery and Simons, 2015). However, to date, attempts to empirically show such a correlation have failed (Sinclair et al., 2016). This is confirmed in the present study in which no significant correlation was found between the composite score of alcohol attentional bias and depressive symptomatology measure with the CES-D.

Finally, we were interested to test whether the assessment of alcohol attentional biases is affected by the sense of presence in the virtual environment. Previous studies (Hernández-Serrano et al., 2020; Simon et al., 2020) suggest that the sense of presence and especially the perceived realism of the virtual environment is important to induce alcohol craving. However, it is unknown whether the sense of presence also affects the magnitude of alcohol attentional biases in a virtual environment. In the present study, we found no significant correlation between the composite score of alcohol attentional bias and the sense of presence as assessed with the Gatineau Presence Questionnaire. Unfortunately, this questionnaire is designed to address the spatial presence in the virtual environment and the plausibility of the situation more than the perceived realism of the environment. The lack of correlation with the composite score of alcohol attentional bias might therefore be interpreted in two ways. It is possible that alcohol attentional bias in a virtual environment is less affected by the sense of presence than alcohol craving. However, it is also possible that the Gatineau Presence Questionnaire does not accurately assess the most important dimension of the presence for alcohol attentional biases, namely the perceived realism of the virtual environment. Further studies will be required to answer this question.

4.4 Limits and perspectives

4.4.1 Limits

Although the present study successfully shown that alcohol attentional biases can be assessed in a virtual environment, some limitations must be acknowledged. Firstly, the current study was restricted to a non-clinical population of young social alcohol drinkers. It will be important to replicate the current study in a clinical sample of people with alcohol use disorders, who hold stronger alcohol attentional biases according to the theoretical model of Field and Cox (2008) and the empirical literature (Lusher et al., 2004; Fadardi and Cox, 2006). Secondly, the present study was exploratory in nature. As one of the exploratory goals was to test which predefined cues might or might not relate to alcohol craving and consumption, a stricter control of statistical type I error rate was not applied to the multiple correlations. Additionally, the composite score of alcohol attentional bias was created a posteriori using an inductive procedure from individual correlations. Although the results clearly show significant correlations with predefined alcohol cues, but not with predefined neutral cues, a validation of the composite score will require a replication study.

Another limitation of the present study pertains to the tradeoffs between experimental control and ecological validity. Dot probe tasks and other cue exposure computer tasks heavily rely on contrasting alcohol cues with control cues. The strength of these techniques lies in the experimental control over the stimuli, as they usually oppose very comparable alcohol and control cues, with a strict control over their properties, such as color, brightness, saliency, size and so on. However, such a strict experimental control is obtained at the expense of the ecological validity of the tasks (for a critical review see Christiansen et al., 2015a; Field et al., 2016; Rodebaugh et al., 2016). The use of virtual reality to study alcohol-related attentional biases presents the opposite strengths and weaknesses. It is much closer to how attentional biases work in a natural setting, especially because attention may be tested while the participant is immersed in an alcohol-related context. The tradeoff, however, is that the technique does not allow a strict control on the visual cues seen by the participants. A participant may even miss a significant stimulus in the environment if he never watches in its direction. This why in the present study, alcohol-related cues were not matched one-to-one with control cues similar in color, size or saliency, as it is generally the case with dot probe tasks.

Additionally, it should be noted that the data was collected during the COVID-19 pandemic. During this particular period, dramatic changes in the pattern of alcohol consumption were reported (Pabst et al., 2021). In general, alcohol consumption decreased in Europe due to the closure of bars, restaurants and nightclubs (Kilian et al., 2021), while other studies suggested a slight increase in consumption (Vanderbruggen et al., 2020). This might have affected some of the results in the present study, and especially the AUDIT questionnaire. Indeed, this questionnaire assesses harmful alcohol use during the current year. The AUDIT scores of the participants might therefore capture their unusual patterns of alcohol consumption during the COVID-19 pandemic rather than their more general alcohol consumption tendencies. This could have affected the correlations with alcohol attentional biases and may help to explain why stronger correlations were found with OCDS subscales.

It is postulated that attentional biases for drug-related cues show a fair degree of stability across contexts and time. Once attentional biases have developed, they are not easily affected by the availability of the substance in the environment (Wilcockson et al., 2019). However, the magnitude of attentional biases could fluctuate with current motivational (Hobson et al., 2013; Ramirez et al., 2015; Bollen et al., 2020; Soleymani et al., 2020), emotional (Grant et al., 2007; Bollen et al., 2020) and stress states (Field and Quigley, 2009). Attentional biases might therefore fluctuate according to transitional changes in the appetitive and/or aversive motivational states of the participants (Field et al., 2016). In future studies, it might be interesting to test for correlations of the attentional biases in a virtual environment with phasic rather than tonic measures of craving. These technical limitations should soon be overcome as many researchers are now working to improve the gaze tracking data collection in 3D space (Clay et al., 2019).

As the present study developed a new paradigm for the measurement of attentional focus in a virtual environment, it was not easy to transpose usual features of eye tracking techniques, such as measures of ocular saccades or first ROI visited. Another limitation intrinsically related to the naturalness of the paradigm is the fact that participants were free to blink during the whole experiment, which might have reduced the number and duration of fixations. Finally, as Roy-Charland et al. (2017) study showed, in order to most effectively measure attentional biases in complex scenes, it is important to ensure full attention to the scene. As the main benefit of VR is to allow participants to freely explore an immersive environment, we chose to minimize the instructions given to the participants about their task in the virtual environment. From the debriefing, it was apparent that participants developed various hypotheses about the goal of the study that might have interfered with their attentional focus on specific cues. In future studies, it might be useful to provide participants with more specific instructions.

4.4.2 Perspectives and futures questions

The experimental paradigm developed in the present study will be useful to further investigate alcohol-induced attentional biases in subclinical and clinical populations of alcohol consumers.

In particular, future studies might use the present paradigm to test the correlation between attentional biases for alcohol-related cues and phasic craving concurrently induced by those cues during the immersion in the virtual environment. In that context, questions remain about what substance-related items to include in virtual environments to induce high levels of phasic craving. According to Pericot-Valverde et al. (2016), substance-related cues can be divided into three categories: proximal, contextual, and complex cues. Proximal cues include all specific objects that are typically associated with the substance. Contextual cues include the physical settings or situations where drugs are used, such as a party or a bar. The settings typically associated with the highest levels of craving are party venues, restaurants, bars or pubs, nightclubs, or being at home (Monk and Heim, 2014; Ghiţă et al., 2019). Finally, complex cues are a combination of contextual and proximal cues, such as situations involving social interactions, where people are dancing, drinking alcoholic beverages, etc. Relative to the more traditional eye tracking paradigm, ET-VR allows studying attentional biases for various alcohol proximal cues while the participant is immersed in an alcohol-related virtual environment (i.e., complex cues). The choice of the proximal and contextual cues incorporated into the virtual environment is therefore a parameter that can strongly affect the intensity of craving and attentional biases, as well the time course of their correlation (Drummond, 2001; Fadardi et al., 2006; Bordnick et al., 2008; Field and Cox, 2008). Additionally, VR allows the personalization of alcohol proximal cues, for example by taking into account the preferred alcoholic beverage(s) of the participant. Therefore, the features of the virtual environment that allow the expression of high levels of alcohol craving and attentional biases are important parameters to investigate. Several authors suggest that a sufficient level of presence during the immersion is necessary for the expression of emotional responses, such as craving (Riva et al., 2007; Diemer et al., 2015). The different dimensions of the sense of presence could therefore mediate or moderate the expression of phasic alcohol craving and attentional biases, as well as their relationships. Based on previous results, the degree of realism (Hernández-Serrano et al., 2020; Simon et al., 2020) and the social nature of the virtual environment (Bordnick et al., 2008) could be two interesting parameters to explore. Embodiment (which is defined as the total or partial representation of the user's body in a virtual body) is also another parameter that could help the user to immerse himself in the environment (Kilteni et al., 2012) and increase the craving and the attentional bias.

Technological advances, and in particular ET-VR devices, offer new diagnostic and clinical tools for patients with alcohol use disorders. With these techniques, an evaluation of the level of craving combined with attentional biases could be integrated into the diagnostic assessment of the patients. In some cases, patients (and their relatives) may adopt a defensive position by communicating erroneous, incomplete or unsatisfactory information, especially if they are in denial about the disease. Using less explicit measures would therefore improve the assessment of the severity of the disorder. Similarly, it is expected that effective treatments reduce both craving and attentional biases. Their assessment through VR could then be used as a measure of treatment effectiveness (Martingano and Persky, 2021).

Several tasks based on classical paradigms were developed to increase the inhibitory control of eye movements to help patients reduce their attentional biases. Such training was shown to reduce the magnitude of attentional biases for alcohol-related cues (Schoenmakers et al., 2010; Wiers et al., 2011; Lee and Lee, 2015; Clerkin et al., 2016; Rinck et al., 2018). However, while many studies still consider attentional bias modification as a promising therapeutic tool, its clinical relevance has been recently questioned, especially due to the low internal reliability of the tasks (Christiansen et al., 2015b). ET-VR devices might be useful to make patients aware of their biases in psycho-educational session and could even be used to train disengagement strategies to decrease the attentional attractiveness of alcohol cues. Finally, ET-VR devices could be integrated into Virtual Reality-based Exposure Therapies (VRETs). This should enhance patient self-regulation and self-efficacy to promote sustainable behaviour changes and improve their management of cue reactivity (Segawa et al., 2020).

5 Conclusion

The present study shows that alcohol-induced attentional biases can be successfully studied using an ET-VR device in a subclinical population of alcohol users. The dwell time and the number of fixations towards alcohol-related cue were positively correlated with the drinking motivation of the participants and to a lesser extent with their individual consumption trends, whereas no significant correlation was found for neutral stimuli. Furthermore, the number of fixations appears to be a more robust measure than the dwell time in terms of the correlation sizes and the internal consistency of the measure.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://osf.io/438mn/?view_only=c10c7c8e67aa48f5adf1327c58d894a4.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics committee of the Faculty of Psychology, Speech Therapy, and Educational Science of the University of Liège. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JS, EQ, and SB: idea and implementation of experimental design. DG: technical developments allowing the integration of eye tracking devices on VR headset and exportation of recording data. SB: provision of the virtual environment. M-CR: integration of the eye tracking system in the virtual environment and the implementation of colliders. JS and MH: data collection and data processing. JS, EQ, and MH: statistical analyses. JS, EQ, and DG: manuscript writing. MH, SB, and M-CR: manuscript reviewing.

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Conflict of interest

SB is the president of and own equity in Cliniques et Développement In Virtuo, a university spin-off that uses virtual reality as part of its clinical services and distributes virtual environments. The terms of this arrangement have been reviewed and approved by the Université du Québec en Outaouais in accordance with its conflict of interest policies

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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