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Exploring Attentional Bias toward Alcohol Content: Insights from Eye-Movement Activity

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Keywords

Attentional bias · Visual attention task · Drinking patterns · Alcohol use disorder · Eye-tracking technology

Abstract

Introduction: Attentional bias (AB) is an implicit selective attention toward processing disorder-significant information while neglecting other environmental cues. Considerable empirical evidence highlights the clinical implication of AB in the onset and maintenance of substance use disorder. An innovative method to explore direct measures of AB relies on the eye-movement activity using technologies like eye-tracking (ET). Despite the growing interest regarding the clinical relevance of AB in the spectrum of alcohol consumption, more research is needed to fully determine the AB patterns and its transfer from experimental to clinical applications. The current study consisted of three consecutive experiments. The first experiment aimed to design an ad-hoc visual attention task (VAT) consisting of alcohol-related and neutral images using a nonclinical sample ($n = 15$). The objective of the second and third experiments was to analyze whether the effect of type of image (alcohol-related vs. neutral images) on AB toward alcohol content using the VAT developed in the first experiment was different for type of drinker (light vs. heavy drinker in the second experiment [$n = 30$], and occasional social drinkers versus alcohol use disorder (AUD) patients in the third experiment [$n = 48$]). ***Methods:*** Areas of interest (AOIs) within each type of image (neutral and alcohol-related) were designed and raw ET-based data were subsequently extracted through specific software analyses. For experiment 1, attention maps were created and processed for each image. For experiments 2 and 3, data on ET variables were gathered and subsequently analyzed through a two-way ANOVA with the aim of examining the effects of the type of image and drinker on eye-movement activity. ***Results:*** There was a statistically significant interaction effect between type of image and type of drinker (light vs. heavy drinker in experiment 2, $F(1, 56) = 13.578$, $p < 0.001$, partial $\eta^2 = 0.195$, and occasional social

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drinker versus AUD patients in the experiment 3, $F(1, 92) = 35.806$, $p < 0.001$, partial $\eta^2 = 0.280$) for "first fixation" with large effect sizes, but not for "number of fixations" and "dwell time." The simple main effect of type of image on mean "first fixation" score for AUD patients was not statistically significant. ***Conclusion:*** The data derived from the experiments indicated the importance of AB in sub-clinical populations: heavy drinkers displayed an implicit preference for alcohol-related images compared to light drinkers. Nevertheless, AB fluctuations in patients with AUD compared to the control group were found. AUD patients displayed an early interest in alcohol images, followed by an avoidance attentional processing of alcohol-related images. The results are discussed in light of recent literature in the field.

Introduction

Attentional bias (AB) is an implicit selective attention toward processing disorder-significant information while neglecting other environmental cues [1–3]. Considerable empirical evidence highlights the clinical implication of AB in the onset and maintenance of substance use disorder [4–9].

The incentive sensitization theory brings forward the neurobiological mechanisms of addiction explaining that repeated exposure and alcohol consumption result in acquiring a high-gratification potential of alcohol-related cues and contexts [10–12]. Facilitated by AB and accompanied by a positive rewarding valence, alcohol-seeking and -drinking behaviors are further encouraged [2, 11]. This cycle explains the "neuroadaptation" baseline of addiction, in which alcohol-related stimuli acquire high motivational properties (incentive salience) by promoting the excessive sensitization of the dopamine response in the brain. Over time, alcohol-related cues facilitate hijacking of the reward system in which the individual's attention focus is on the gratifying cues (alcohol). This alcohol-related AB further encourages drinking-related behaviors (known as approach behaviors) as a result of implicit ("unconscious wanting") or explicit ("conscious craving") processes [13, 14].

In alcohol use disorder (AUD), the dual process model emphasizes the interplay between the "reflective system" (controlled, deliberate responses governed by emotion regulation and expected outcomes) and the "reflexive system" (implicit appraisal of appetitive/alcohol-related stimuli) [15, 16]. Decision-making reflects an imbalance between the two systems and an enhanced reflexive system ("impulsive system") may facilitate implicit responses that favor the approach of alcohol-related stimuli [5, 9]. Previous studies have highlighted that AB toward alcohol content and alcohol craving (i.e., obsessive alcohol-related thoughts and compulsive urge to drink alcohol) are among the underlying mechanisms of the development and maintenance of AUD [2, 17, 18].

Regarding the assessment of AB, alcohol-related AB can be measured directly (e.g., by monitoring eye movements), or it can be indirectly inferred with reaction time or other measures. Many studies have focused on reaction time, and the modified Stroop and visual probe tasks are commonly used tasks [1–3, 19]. Considering the addiction Stroop task, the reaction time-based ABs are more pronounced in individuals with substance use disorder compared to control participants. In a visual probe task, light drinkers do not display a bias toward alcohol cues, while heavy drinkers show AB for alcohol cues. However, patients with AUD in active treatment avoid paying attention to alcohol cues (see review [2]). Reaction time-based measures of AB have been criticized for their low internal reliability, due to ambiguity about the attentional subcomponents that they measure, ecological validity, psychometric properties, and disregard for the dynamic nature of attentional processes [6, 19–22].

A more innovative method to explore direct measures of AB relies on the eye-movement activity through the use of technologies like eye-tracking (ET) [3, 9]. The ET technology facilitates the detection of oculomotor activity such as eye gaze, position, or movement. AB can be examined through several eye-movement parameters measured by the ET technology with the aim of detecting early-stage implicit attention, as well as maintenance-stage, voluntary, and deliberate cognitive processing [9]. Some of the parameters derived from the ET technology are pupillary dilation [8], saccades [23], first fixation [3, 23–28], number of fixations [22–24], or dwell time [3, 19, 24, 26–29]. For instance, first fixation reflects an early-stage attention processing, the first fixation or gaze point on a stimulus, whereas dwell time (total fixation time) and number of fixations reflect maintenance-stage, voluntary, and deliberate attention processing. A previous study found that alcohol-AB was depicted through total fixation time (dwell time) in heavy drinkers compared to light drinkers [30]. A comprehensive systematic review with 95 studies determined the link between AB and alcohol use patterns [14]. The authors challenged the stability of AB in clinical populations by emphasizing that AB for alcohol content is dependent on alcohol craving or drinking status. Moreover, considering the unstable nature of AB in AUD, this interferes with the approach-avoidance behavioral patterns that have previously been emphasized in the AB and addiction literature [14]. Nevertheless, in the studies with subclinical populations, AB is a "robust" attention process toward alcohol content as depicted by dwell time in heavy drinkers but not in light drinkers.

Despite the growing interest regarding the clinical relevance of AB in the spectrum of alcohol consumption, more research is needed to fully determine the AB patterns and its transfer from experimental to clinical applications [5]. Thus, the current study consisted of three consecutive experiments. Each experiment focused on a specific objective, as follows:

Experiment 1 aimed to create an ad hoc visual attention task (VAT) based on the selection of highly salient alcohol- and neutral images. Previous studies implemented in their experiments matched alcohol- and neutral images in terms of composition and background, without determining technical features of the stimuli like contrast, perceptual complexity, or brightness. The emphasis was rather placed on the target stimulus that was either alcohol-related or neutral [28, 31, 32]. Designing the VAT consisted in selecting alcohol-related and neutral images with different backgrounds and compositions and analyzing them by taking into account the clearest absolute salience properties of the images: the physical feature of a stimulus to stand out from its context [33].

Experiment 2 aimed to analyze whether the effect of the type of image (neutral vs. alcohol-related images) on AB toward alcohol content using the VAT developed in the first experiment (ET variables: first fixation, number of fixations and dwell time [3, 9, 24, 25, 27]) was different for the type of drinker (light vs. heavy drinkers). Experiment 3 aimed to examine whether the effect of the type of image (alcohol-related vs. neutral images) on AB toward alcohol content using VAT developed in the first experiment (variables: first fixation, number of fixations, and dwell time) was different for the type of drinker (occasional social drinkers vs. AUD patients).

Materials and Methods

Participants

Demographic data and psychological characteristics of drinking patterns are described in Table 1. In our study, light drinkers are defined as individuals with minimal alcohol use across (social) circumstances. Occasional social drinkers are individuals who use alcohol in moderate amounts mostly on a (occasional) social basis. Heavy drinkers are defined as individuals who use five or more standard drinks per drinking occasion in males, and four or more standard drinks per drinking occasion in females [34]. Patients represent the clinical sample in our study and reflect individuals who are in active treatment at the hospital for AUD.

Experiment 1 included fifteen college students (1 male and 14 females [M_{age} = 22.0, SD = 4.63]). Inclusion criteria were being over 18 years of age, and having normal or corrected-to-normal visual acuity. A heavy drinking pattern represented an exclusion criterion.

Experiment 2 encompassed thirty college students (6 men and 24 women [M_{age} = 22.0, SD = 4.29]). Inclusion criteria were being over 18 years of age and having normal or corrected-to-normal visual acuity. The participants were divided into two groups based on the AUDIT cut-off score (e.g., less than 7 for male light drinkers and less than 5 for female light drinkers, as suggested by [35]). Accordingly, 18 of the participants were light drinkers (AUDIT, M = 1.89, SD = 1.23) and 12 were heavy drinkers (AUDIT, M = 7.33, SD = 2.90).

Experiment 3 included forty-eight individuals: 22 occasional social drinkers (5 males and 17 females; M_{age} = 22.0, SD = 4.6) and 26 AUD patients (15 males and 11 females; M_{age} = 53.0, SD = 11.4). For the occasional social drinkers group, the inclusion criteria were being over 18 years of age, normal or corrected-to-normal visual acuity, and having a total AUDIT score of less but including 5 for female occasional social drinkers, and less but including a score of 7 for male occasional social drinkers [35]. The clinical group consisted of outpatients under ambulatory care diagnosed with AUD. Inclusion criteria for this group were being over 18 years of age and with corrected-to-normal visual acuity. AUD patients were recruited from the Addictive Behaviors Unit of the Hospital Clinic of Barcelona.

Instruments

Alcohol Use Disorders Identification Test (AUDIT), Spanish version [36] was used to screen patterns of alcohol consumption. It consists of a 10-item scale, in a 0-to-40 score range, aiming to determine the problematic use of alcohol [37]. A score ≥8 points indicates hazardous drinking patterns, and further evaluation may determine AUD.

The VAT was developed as an ad-hoc instrument consisting of alcohol-related and neutral images. For alcohol-related images, the results of the Spanish National Health Survey on Alcohol Consumption [38] were initially reviewed, and the outcomes of the survey indicated that beer, wine, and liquors were the most frequently consumed alcoholic beverages. Thus, from the Pixabay database (https://pixabay.com), a total of 88 alcohol-related images clearly reflecting alcohol use preferences (beer, wine, and liquors such as whiskey, vodka, or brandy) were selected. Regarding the neutral images, office-related objects were selected, as in previous studies and protocols [39–41]. Some examples of the aforementioned images are shown in Figure 1.

Hardware. The ET equipment consisted of the Gazepoint GP3 HD eye tracker (150 Hz system, 0.5–1.0 degree of visual angle accuracy, 35 cm (horizontal) × 22 cm (vertical) movement, and ±15-cm range of depth movement) to record eye movement activity, a laptop, a 19″ monitor to display the VAT at a resolution of 1,280 × 1,024, and a chin-rest to avoid head movements. This equipment and technical specifications were used in all three experiments.

ET indexes. The first area of interest (AOI) visited indicates the first area fixated (i.e., initial attentional capture). The first fixation duration indicates the length of the first AOI visited (i.e., persistence of attentional focus). The second AOI visited indicates how frequently the participant fixated a second AOI after visiting the first one (i.e., attention switch). The dwell time is the sum of fixation times on each AOI during the entire trial. Gaze samples were qualified as fixations according to the standard algorithms of the software.

Table 1. Demographic data and psychological characteristics by drinking patterns

Characteristics	Experiment 2		Experiment 3	
	light drinking	heavy drinking	occasional social drinking	patients with AUD
Gender, *n* (%)				
Male	5 (27.8)	1 (8.3)	4 (18.2)	15 (57.7)
Female	13 (72.2)	11 (91.7)	18 (81.8)	11 (42.3)
Civil status, *n* (%)				
Single/in a relationship	18 (100)	12 (100)	22 (100)	4 (15.4)
Married	–	–	–	13 (50)
Separated/divorced	–	–	–	8 (30.8)
Widower	–	–	–	1 (3.8)
Education, *n* (%)				
General certificate of secondary education	–	–	–	–
General certificate of education	–	–	–	7 (26.9)
Vocational education and training	–	–	–	8 (30.8)
University degree	18 (100)	12 (100)	22 (100)	11 (42.3)
Master's degree	–	–	–	–
Doctorate (PhD)	–	–	–	–
Dual pathology, *n* (%)				
Borderline personality disorder	–	–	–	3 (11.5)
Post-traumatic stress disorder	–	–	–	1 (3.8)
Cocaine use disorder	–	–	–	1 (3.8)
Mild cognitive impairment	–	–	–	1 (3.8)
Depressive disorder	–	–	–	6 (23.1)
Compulsive gambling	–	–	–	1 (3.8)
No dual pathology	–	–	–	13 (50.2)
Medication, *n* (%)				
Yes	–	–	–	17 (65.4)
No	–	–	–	9 (34.6)
Age, mean (SD)	22.39 (4.40)	23.58 (4.20)	23.05 (4.54)	53.4 (11.41)
AUDIT, mean (SD)	1.89 (1.23)	7.33 (2.90)	2.68 (1.64)	19.0 (9.52)

AUDIT, Alcohol Use Disorder Identification Test.

Procedures

The current study is part of a larger project named "ALCO-VR," which is aimed at developing and testing assessment and treatment instruments based on technologies such as ET and virtual reality in the spectrum of problematic alcohol consumption. Regarding experiment 1, the sequence of the development of VAT was as follows: (1) selection of images with centered target stimulus (88 alcohol vs. 88 office-related stimuli); (2) analysis of the images considering its absolute salience (high vs. low salience) through the outputs of attention maps from MATLAB; (3) development of a top-down hierarchy with alcohol-related and neutral images from high salience (centered attention) to low salience (non-centered attention); (4) selection of the first 24 images with the most clear absolute salience (12 alcohol-related and 12 neutral images) from the hierarchy based on participants' oculomotor performance. Examples of the attention maps with high vs. low salience are shown in Figure 2. (5) Regarding the final 12 alcohol-related stimuli, 33% of the images focused on beer, 33% on wine, and 33% on liquor-related stimuli. (6) The final version of the VAT consisted of pairs of alcohol-neutral images, and each alcohol image from the 12 alcohol-related images was paired with each of the other 12 neutral images, resulting in 144 pairs of alcohol-neutral images. (7) All images were counterbalanced (i.e., each image appeared the same number of times on both sides of the screen). The VAT was subsequently implemented in experiments 2 and 3.

For experiments 1 and 2, college students were recruited from the University of Barcelona, through the Virtual Campus. Both experiments took place at the Faculty of Psychology, University of Barcelona. Regarding Experiment 1, participants were informed and asked to complete the AUDIT. Prior to the VAT itself, a calibration task was performed to map eye positions. Then, the task was presented to the participants as a false memory task (with the aim of sustaining attention throughout the trials). Images were presented in a one-by-one basis, and grouped into trials. Each trial

Fig. 1. Examples of images used in the VAT – first version.

consisted of ten images with alcohol-related and neutral content. After each trial, participants were asked to report whether a certain image on the screen belonged to the previously presented trial by choosing "yes" or "no." Each image appeared on the screen for 3 s. After each image, a gray background appeared for 1 s with a fixation point at the center of the screen to return the gaze to a focal point. The entire experimental procedure lasted approximately 60 min. Concerning experiment 2, heavy drinkers and light drinkers completed the AUDIT, followed by the VAT. Participants were informed that they were about to explore two images with different content at the same time over several trials. At the end of each trial, participants were asked to report whether a certain image on the screen belonged to the previously presented trial by choosing "yes" or "no." Each pair of images appeared on the screen for 3 s. After each pair of images, a gray background appeared for 1 s with a fixation point at the center of the screen to return the gaze to a focal point. The procedure lasted approximately 20 min.

Concerning experiment 3, AUD patients in the clinical group were informed about this study during their appointments with a healthcare professional at the Addictive Behaviors Unit of the Hospital Clinic of Barcelona. Once the patients agreed to participate, they were referred to the researcher in charge of the study. A short clinical anamnesis was previously conducted to gather important data (e.g., use of anxiolytics, anti-depressants, and disulfiram). Subsequently, patients were asked to complete the AUDIT and the VAT (the VAT-procedure was the same as in Experiment 2). Regarding the occasional social drinkers group, participants were recruited through the Virtual Campus of the University of Barcelona. They completed the AUDIT and the VAT. The experiment took place at Faculty of Psychology, University of Barcelona for the occasional social drinkers group and at Addictive Behaviors Unit, Hospital Clinic of Barcelona for the clinical group. The procedure was the same as in the experiment 2.

Figure 3 displays the schematic representation of the procedures. Written informed consent was obtained from all study participants for participation in the study. The study protocol was reviewed and approved by the Ethics Committees of the University of Barcelona and Hospital Clinic of Barcelona, approval number 0377 (HCB/2017/0377).

Statistical Analysis

The Open Gaze and Mouse Analyzer (Ogama) software was used to design AOIs within each image (AOI-alcohol, AOI-neutral), and extract the raw ET data. AOIs had identical sizes across images. In experiment 1, attention maps were created and processed for each image using MATLAB (MathWorks, Natick, MA, USA) on the ET data. Attention maps showed the absolute salience of each image. For experiment 2, within each AOI, three dependent variables were computed: dwell time, number of fixations, and first fixation. In addition, two independent variables were added: type of image (alcohol-related vs. neutral images) and type of drinker (light vs. heavy drinker). In experiment 3, as in experiment 2, the Ogama software was used to extract the raw eye-movement data and to determine the AOI of each image. Within each AOI, dwell time, number of fixations, and first fixation were evaluated.

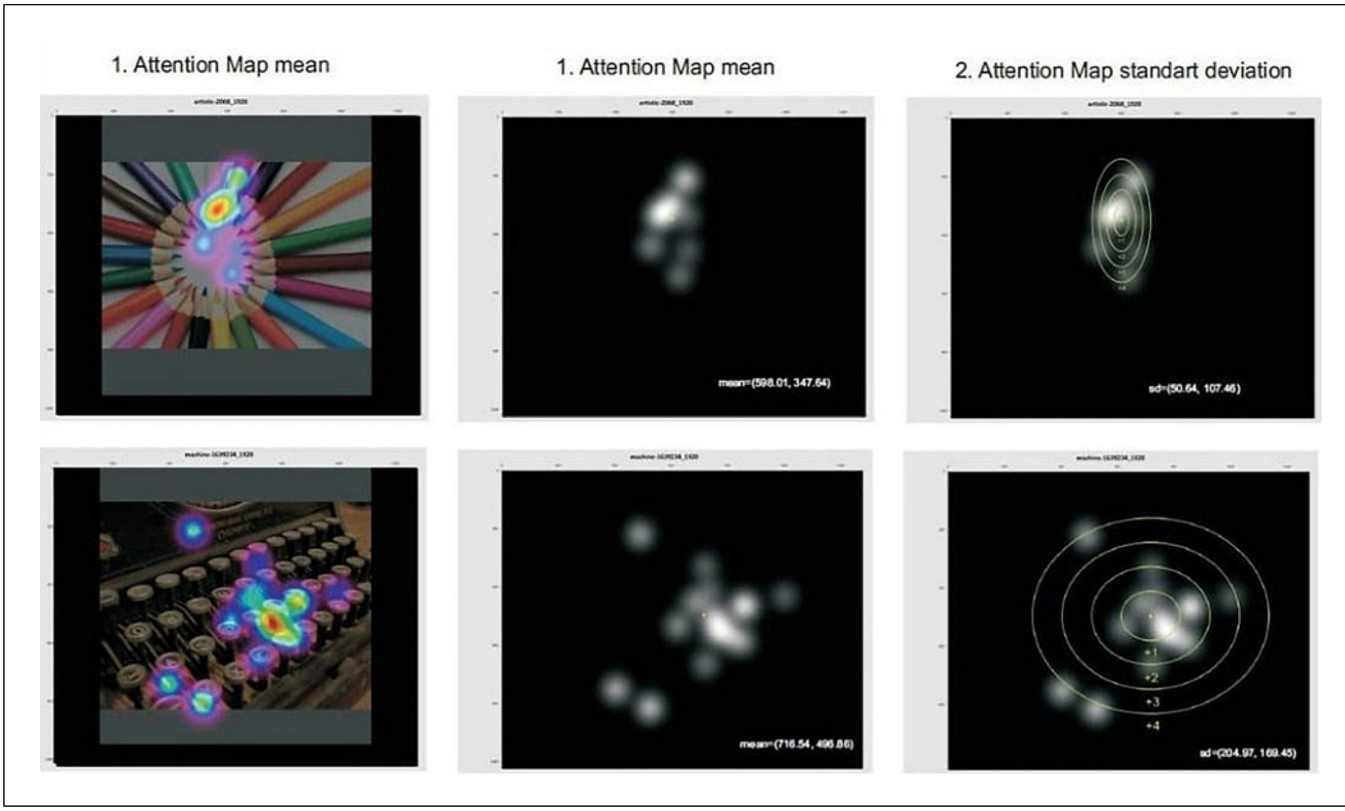

Fig. 2. Examples of attention maps of neutral images from the first version of the VAT. The top-left picture (pencils) reflects an attention map with high salience (centered attention or focal point), whereas the bottom-left picture indicates non-centered (dispersed) attention.

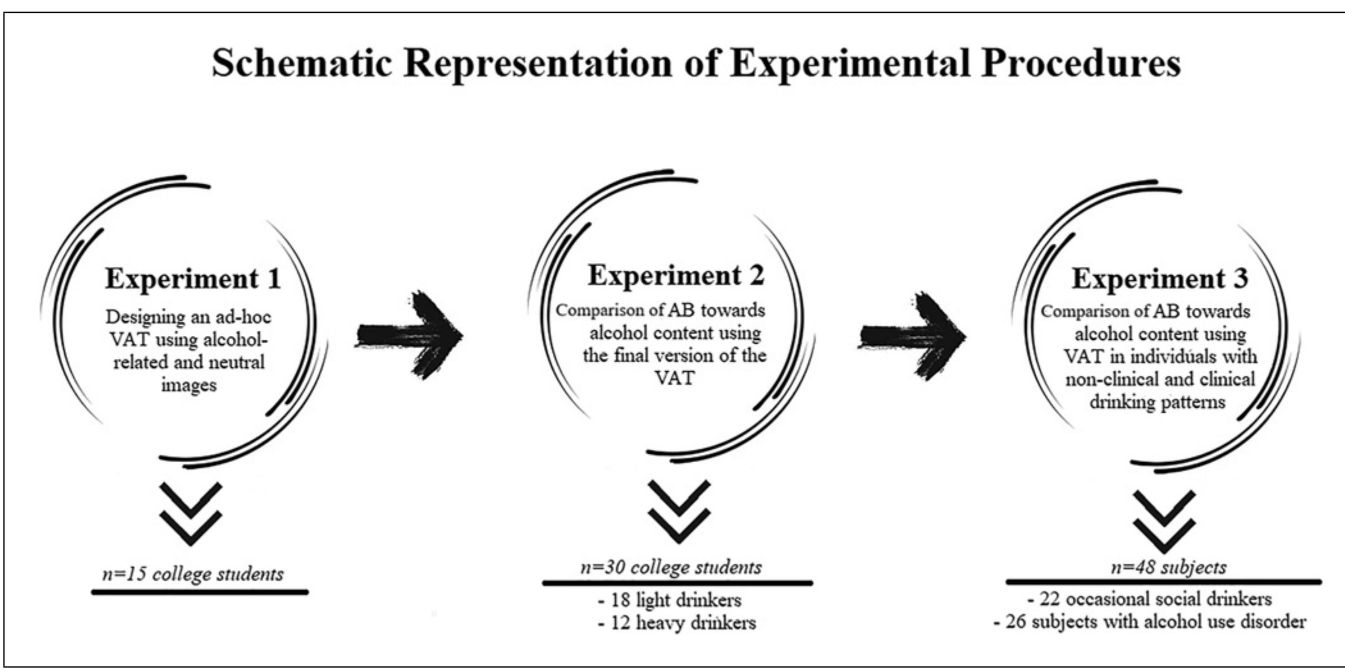

Fig. 3. Schematic representation of the procedure.

Two independent variables were included: type of image (alcohol-related vs. neutral images) and type of drinker (occasional social drinkers vs. AUD patients).

A two-way ANOVA was conducted to examine the effects of type of image (alcohol-related vs. neutral images) and type of drinker (light vs. heavy drinkers in the second experiment, and occasional social drinkers vs. AUD patients in the third experiment) on eye-movement activity (ET variables: first fixation, number of fixations, and dwell time). The emphasis of the analyses was on the interaction between type of image and type of drinker for first fixation, number of fixations, and dwell time. If interaction effects were significant, simple effects were carried out.

Residual analysis was performed to test for the assumptions of the two-way ANOVA. Outliers were assessed by inspection of a boxplot, normality was assessed using Shapiro-Wilk's test and homogeneity of variances was assessed by Levene's test. Data were analyzed with SPSS 27.0 (IBM, Armonk, NY, USA).

Results

Experiment 1

Participants displayed a nonclinical (light) drinking pattern (AUDIT; M = 2.13, SD = 2.87). Considering the protocol for the VAT development as depicted in the Procedure sub-section, analyses to control for brightness, contrast, and perceptual complexity [42] to avoid bias as a result of picture technical characteristics [43] were performed. These analyses showed no statistically significant differences between the 12 images with alcohol content versus the 12 images with neutral content ($p > 0.05$). The final version of VAT consisted of matching these remaining 12 alcohol images and 12 neutral images in alcohol-neutral pairs, which was subsequently used in the second and third experiments.

Experiment 2

Data followed a normal distribution with no outliers ($p > 0.05$), and homogeneity of variances was stated ($p > 0.05$). Table 2 shows means, standard deviations, and 95% confidence intervals of type of drinker (light vs. heavy drinkers) and type of image (neutral vs. alcohol-related images) for "first fixation," "number of fixations," and "dwell time," as well as the results from the two-way univariate ANOVA comparing type of drinker and type of image for "first fixation," "number of fixations," and "dwell time."

Interaction Effects

There was a statistically significant interaction between the type of image (neutral vs. alcohol-related images) and type of drinker (light vs. heavy drinkers) for "first fixation" with large effect sizes [44], $F(1, 56) = 13.578$, $p < 0.001$, partial $\eta^2 = 0.195$. Figures 4 and 5 show an interaction effect between the independent variables (type of image and type of drinker) on the "first fixation." However, there was no statistically significant interaction between type of image (neutral vs. alcohol-related images) and type of drinker (light vs. heavy drinkers) concerning "number of fixations" and "dwell time" ($p > 0.05$).

Simple Effects

Statistically significant differences were found on the scores of "first fixation" between light and heavy drinkers who focused their attention on neutral images, with medium effect sizes [44], $F(1, 52) = 6.789$, $p = 0.012$, partial $\eta^2 = 0.108$. For light and heavy drinkers who focused their attention on neutral images, the mean "first fixation" scores were 0.545 ± 0.024 and 0.522 ± 0.022 for light and heavy drinkers, respectively, with a statistically significant mean difference of 0.023 (95% CI, 0.005–0.041).

On another note, statistically significant differences, with large effect sizes [44], were found concerning "first fixation" scores between light drinkers who focused their attention on neutral and alcohol-related images, $F(1, 56) = 130.327$, $p < 0.001$, partial $\eta^2 = 0.699$. The mean score for the "first fixation" of light drinkers focusing their attention on neutral images was 0.54 ± 0.02, whilst it corresponded to 0.45 ± 0.02 for light drinkers who focused their attention on alcohol-related images: statistically significant mean differences of 0.091 (95% CI, 0.075–0.107) were found. In the case of heavy drinkers, the mean "first fixation" score was 0.044 (95% CI, 0.025–0.064) points higher for neutral images than for alcohol-related images, with large effect sizes [44], $F(1, 56) = 20.831$, $p < 0.001$, partial $\eta^2 = 0.271$. Mean "first fixation" score for heavy drinkers who focused their attention on neutral images was 0.52 ± 0.02, whereas mean scores for heavy drinkers who focused their attention on alcohol-related images corresponded to 0.47 ± 0.02.

Main Effects

No statistically significant main effects of the type of drinker on "number of fixations" score ($F(1, 56) = 0.000$, $p = 1{,}000$, partial $\eta^2 = 0.000$) and type of image on "number of fixations" score ($F(1, 56) = 0.194$, $p = 0.661$, partial $\eta^2 = 0.000$) were found. In the same line, there was no statistically significant main effect concerning the type of drinker on "dwell time" scores ($F(1, 56) = 0.000$, $p = 1{,}000$, partial $\eta^2 = 0.000$) and of the type of image on "dwell time" scores ($F(1, 56) = 0.213$, $p = 0.646$, partial $\eta^2 = 0.004$).

Table 2. Experiment 2: two-way univariate ANOVA comparing type of drinker and type of images for "first fixation," "number of fixations," and "dwell time"

	Light drinkers (n = 18), M±SD (95% CI)	Heavy drinkers (n = 12), M±SD (95% CI)	Effects	F(p)	η^2
Dwell time					
			Type of drinker -Ref-	0.000 (1.000)	0.000
Neutral images	0.500±0.045 (0.479–0.520)	0.495±0.028 (0.479–0.510)	Type of image	0.213 (0.646)	0.004
Alcohol Images	0.495±0.028 (0.482–0.507)	0.504±0.028 (0.488–0.519)	Type of drinker*Type of image	0.218 (0.642)	0.004
First fixation					
			Type of drinker -Ref-	0.000 (1.000)	0.000
Neutral images	0.545±0.024 (0.533–0.556)	0.522±0.022 (0.509–0.532)	Type of image	115.681 (<0.001)*	0.674
Alcohol images	0.454±0.024 (0.442–0.464)	0.477±0.022 (0.465–0.489)	Type of drinker*Type of image	13.578 (<0.001)*	0.195
Number of fixations					
			Type of drinker -Ref-	0.000 (1.000)	0.000
Neutral images	0.501±0.037 (0.483–0.518)	0.497±0.028 (0.481–0.512)	Type of image	0.022 (0.883)	0.000
Alcohol images	0.498±0.037 (0.480–0.515)	0.502±0.028 (0.486–0.517)	Type of drinker*Type of image	0.194 (0.661)	0.003

M, mean; SD, standard deviation; 95% CI, 95% confidence interval; -Ref-, reference category. *Significant p values <0.05.

Experiment 3

No outliers were found, while residuals were normally distributed ($p > 0.05$), and there was homogeneity of variances ($p > 0.05$). Table 3 shows the results (means, standard deviations, and 95% confidence intervals) of type of drinker (occasional social drinkers vs. AUD patients) and type of image (neutral vs. alcohol-related images) for "first fixation," "number of fixations," and "dwell time," as well as the results from the two-way univariate ANOVA comparing type of drinker and type of image for "first fixation," "number of fixations," and "dwell time".

Interaction Effects

There was a statistically significant interaction between the type of image (alcohol-related vs. neutral images) and type of drinker (occasional social drinkers vs. AUD patients) for "first fixation" score with large effect sizes [44], $F(1, 92) = 35.806$, $p < 0.001$, partial $\eta^2 = 0.280$. Figures 6 and 7 show two profile graphs that represent an interaction effect between the independent variables (type of image and type of drinker) on the first fixation, given that the line-crossing (Fig. 6, 7). However, there was no statistically significant interaction between the type of image (alcohol-related vs. neutral images) and type of drinker (occasional social drinkers vs. AUD patients) for "number of fixations" and "dwell time" scores ($p > 0.05$).

Simple Effects

There were statistically significant differences on the mean scores of "first fixation" between occasional social drinkers and AUD patients who focused their attention on alcohol-related images, with small effect sizes [44], $F(1, 92) = 17.903$, $p < 0.001$, partial $\eta^2 = 0.163$. For occasional social drinkers and AUD patients who focused their attention on alcohol images, mean "first fixation" scores for occasional social drinkers were 0.45 ± 0.02 and 0.50 ± 0.05 for AUD patients: statistically significant mean differences of 0.050 (95% CI, 0.027–0.074) were found.

There was a statistically significant difference in the mean scores "first fixation" between occasional social drinkers who focused their attention on neutral and alcohol-related images with large effect sizes [44], $F(1, 92) = 46.671$, $p < 0.001$, partial $\eta^2 = 0.337$. Occasional social drinkers mean "first fixation" scores were 0.54 ± 0.02 and 0.45 ± 0.02 for neutral images and alcohol-related images, respectively. Statistically significant mean differences of 0.084 (95% CI, 0.060–0.108) were stated. In the case of AUD patients, although the mean "first fixation" score was

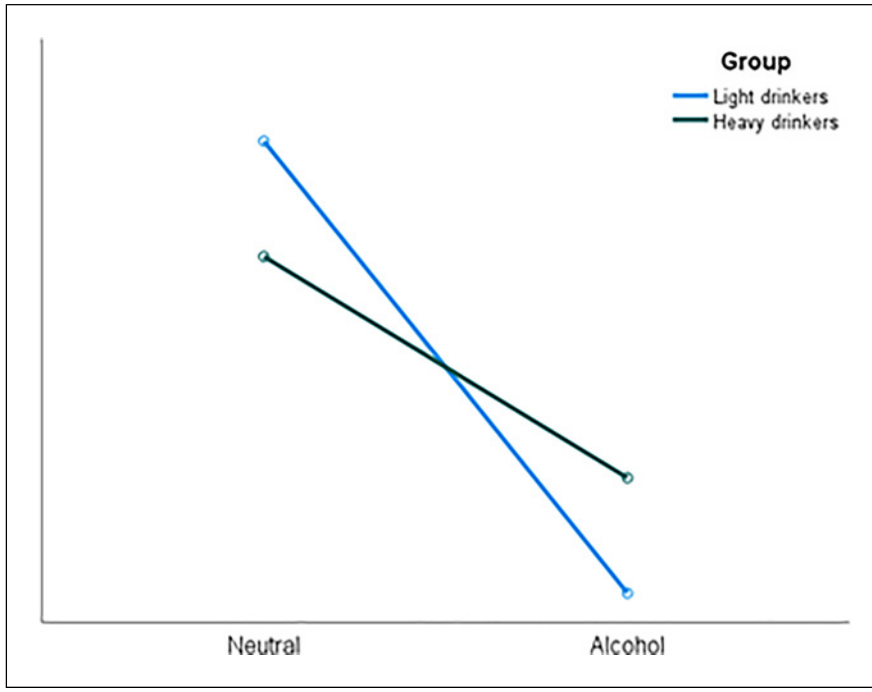

Fig. 4. Experiment 2: interaction effects of type of image and type of drinker on first fixation (plots of light vs. heavy drinkers).

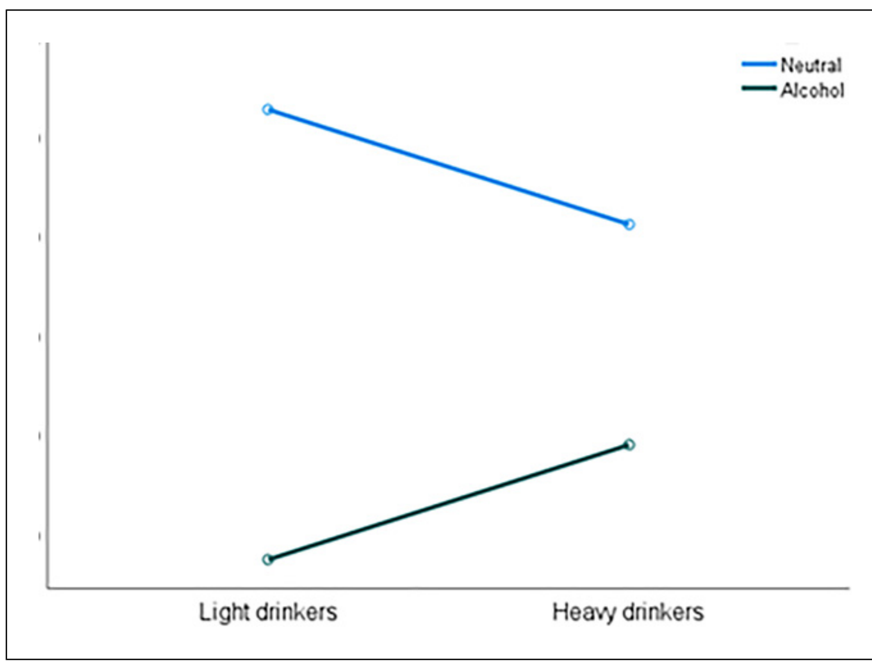

Fig. 5. Experiment 2: interaction effects of type of image and type of drinker on first fixation (plots of neutral vs. alcohol-related images).

0.016 (95% CI, −0.006–0.038) points higher for alcohol-related images than for neutral images, the simple main effect of the type of image on the mean score for "first fixation" for AUD patients was not statistically significant, $F(1, 92) = 1.994$, $p = 0.161$, partial $\eta^2 = 0.271$.

Main Effects

There were no statistically significant differences in the "number of fixations" scores for occasional social drinkers and AUD patients, $F(1, 92) = 0.000$, $p = 1,000$, partial $\eta^2 = 0.000$. However, there was a statistically significant main

Table 3. Experiment 3: two-way univariate ANOVA comparing type of drinker and type of images for "first fixation," "number of fixations," and "dwell time"

	Occasional drinkers (n = 22) M±SD (95% CI)	AUD patients (n = 26) M±SD (95% CI)	Effects	F(p)	η^2
Dwell time					
			Type of drinker -Ref-	0.000 (1.000)	0.000
Neutral images	0.501±0.042 (0.483–0.518)	0.514±0.043 (0.497–0.530)	Type of image	3.212 (0.076)	0.034
Alcohol images	0.498±0.042 (0.480–0.515)	0.485±0.043 (0.468–0.501)	Type of drinker*Type of image	1.877 (0.174)	0.020
First fixation					
			Type of drinker -Ref-	0.000 (1.000)	0.000
Neutral images	0.542±0.023 (0.532–0.551)	0.492±0.050 (0.472–0.511)	Type of image	16.581 (<0.001)*	0.153
Alcohol images	0.457±0.023 (0.447–0.466)	0.507±0.050 (0.487–0.526)	Type of drinker*Type of image	35.806 (<0.001)*	0.280
Number of fixations					
			Type of drinker -Ref-	0.000 (1.000)	0.000
Neutral images	0.504±0.036 (0.488–0.519)	0.515±0.035 (0.501–0.528)	Type of image	7.042 (0.009)*	0.071
Alcohol images	0.495±0.036 (0.479–0.510)	0.484±0.035 (0.470–0.497)	Type of drinker*Type of image	2.157 (0.145)	0.023

M, mean; SD, standard deviation; 95% CI, 95% confidence interval; -Ref-, reference category. *Significant p values <0.05.

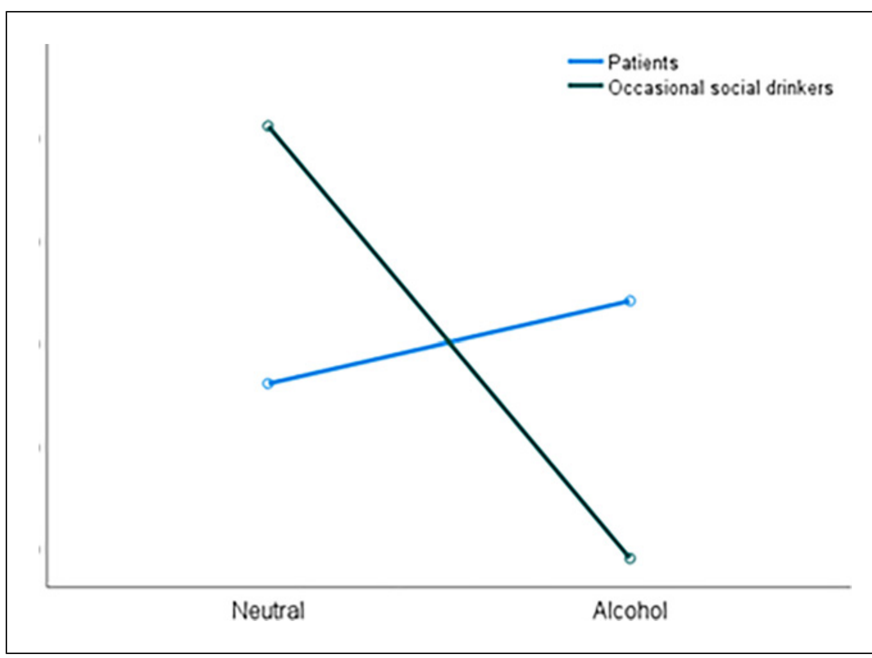

Fig. 6. Experiment 3: interaction effects of type of image and type of drinker on first fixation (plots of AUD patients vs. occasional social drinkers).

effect of type of image on "number of fixations" score with medium effect sizes [44], $F(1, 92) = 7.042$, $p = 0.009$, partial $\eta^2 = 0.071$. The number of fixations was higher for neutral images (0.510 ± 0.005) than for alcohol-related images (0.490 ± 0.005). In relation to the dependent variable "dwell time," no statistically significant main effect was

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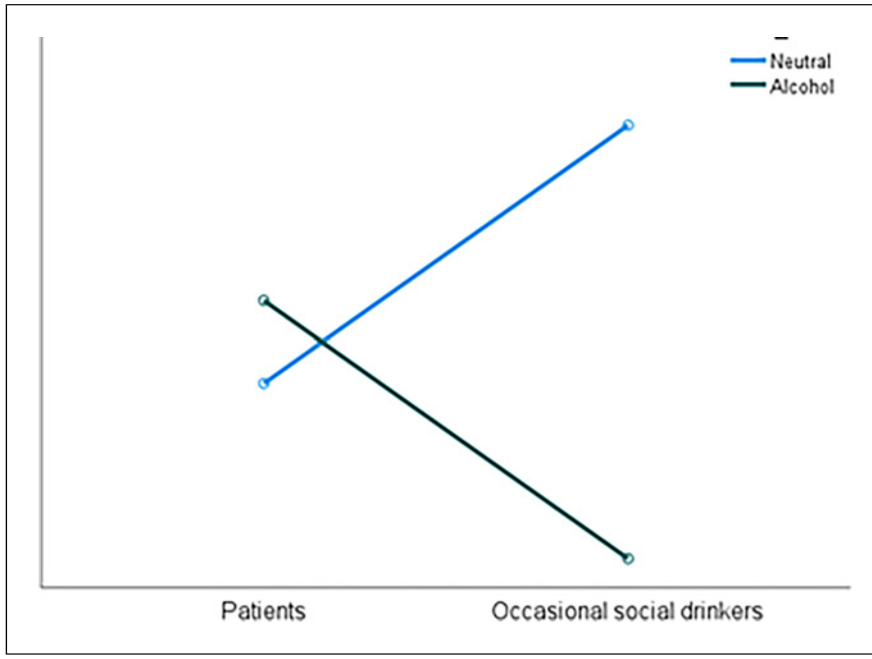

Fig. 7. Experiment 3: interaction effects of type of image and type of drinker on first fixation (plots of neutral vs. alcohol-related images).

observed neither for the type of drinker (occasional social drinkers vs. AUD patients), $F(1, 92) = 0.000$, $p = 1{,}000$, partial $\eta^2 = 0.000$, nor for the type of image on "dwell time" scores, $F(1, 92) = 3.212$, $p = 0.076$, partial $\eta^2 = 0.034$.

Discussion

The current study aimed to develop an ad-hoc VAT to further examine AB in subclinical and clinical samples across three different experiments. A novel approach of designing an ad-hoc VAT consisting of alcohol-related and neutral images is described in Experiment 1, with the use of computational analysis to determine centered attention of different images on alcohol and neutral stimuli. Regarding Experiment 2, for the type of image, both heavy drinkers and light drinkers displayed more of their first gaze (first fixation) toward neutral versus alcohol images. For the type of drinker, heavy drinkers depicted more of their first gaze (first fixation) towards alcohol-related images compared to light drinkers. Conversely, light drinkers displayed more their first gaze toward neutral images compared to heavy drinkers. The results stemming from this second experiment suggest the existence of an AB at an early stage of attentional processing for images with alcohol content in heavy drinkers and an AB for neutral images in light drinkers, but not at late-maintenance levels of attention processing (e.g., dwell time or number of fixations) in both groups. A study by Weafer and Fillmore (2013) [45] indicated that heavy drinkers display an AB for alcohol stimuli compared to the control group. The authors emphasize that displaying such alcohol-related AB may be a motivational component for the onset of a new drinking episode [45].

Considering Experiment 3, in terms of first fixation for the type of image, AUD patients displayed more of their first gaze toward alcohol versus neutral images, unlike occasional social drinkers who fixated more of their first gaze on neutral images. For the type of drinker, AUD patients depicted more of their first gaze towards alcohol-related images compared to occasional social drinkers, while the latter group fixated more on neutral images. In terms of number of fixations, a reversed attention pattern was observed. Occasional social drinkers displayed their attention more on alcohol images compared to AUD patients. And AUD patients displayed more prolonged attention for neutral images compared to occasional social drinkers. The data in the third experiment highlight the fluctuations in AB in AUD patients, having an early-stage AB for alcohol images, followed by late-maintenance attentional interest in neutral images. This is translated into a conscious and voluntary avoidance of alcohol stimuli ("alcohol-related avoidance bias" as indicated by previous research) [46].

AB can be inferred by the time course of attention at two levels: early-state attention processing (first fixation) [9] and maintenance attention processing (number of fixations). Taking the aforementioned into account, data from our experiments indicated that heavy drinkers, occasional social drinkers, and AUD patients display AB toward alcohol content as derived by different time course of attention, whereas light drinkers do not seem to display AB towards alcohol-related images but a preference for neutral images. Previous studies focusing on light drinking state that individuals with a non-clinical drinking pattern do not show a cognitive bias towards alcohol content [2, 6]. Concerning occasional social drinkers' patterns, our results are in line with previous literature depicting AB at a maintenance stage of attention but not at an early-stage attention processing [31]. In contrast, individuals with heavy drinking patterns have an implicit tendency to detect alcohol-related stimuli at early-stage attention as indicated elsewhere [47]. Such pattern is also emphasized in the second experiment of the current research, in which a certain degree of bias is stated at early but not maintenance stage of attention processing in heavy drinkers. Furthermore, other three studies determined a similar time course of attention bias towards alcohol content in AUD individuals [48–50]. These studies highlighted that AUD participants showed an initial orientation pattern, an implicit attention processing for alcohol stimuli, followed immediately by disengaging from sensitive stimuli, and maintenance of attentional focus on neutral stimuli.

A significant body of literature indicates the significance of the dual process model [5, 9, 15], as well as the importance of the incentive-sensitization theory in the development of AUD [10–12]. Considering the dual-process model, the theoretical framework emphasizes the over-activation of the reflexive system (facilitating appetitive processes) and an under-activation of the reflective system (controlled and voluntary processes) within this model, which ultimately impacts the decision-making process in favor of motivationally salient stimuli (e.g., drinking-related behaviors). The dual process model suggests a high sensitivity to alcohol-related cues and contexts as a result of the imbalance between the two systems [5, 9]. Regarding the incentive-sensitization theory, alcohol-related cues become highly motivational, and over time, due to neuroadaptation, the individual's focus is displayed on the appetitive cues (alcohol) [10–12]. In a recent systematic review, the relevance of the dual-process model and the incentive-sensitization theory are challenged with regard to AB in clinical populations [14]. The authors bring forward that AB is rather an unstable cognitive mechanism, particularly in individuals with AUD due to its dependency on alcohol craving or drinking status. Many studies in the review report inconsistency in AB patterns in AUD, and bring forward AB fluctuations in individuals with different drinking patterns. Such patterns can also be observed in our study as well, where AUD patients displayed an initial gaze toward images with alcohol content, followed by an avoidance attentional pattern of these images and focusing more on images with neutral content. This emphasizes the fluctuation component of AB in AUD patients, where patients were capable of actively avoiding alcohol images at the maintenance/late stage of attention processing [14]. This may be in contrast with the "automatic" and "impulsive" nature of AB according to the dual-process model. Considering that AUD patients were in active treatment at the time of their inclusion in this study, the aim of the treatment is on reduction of alcohol consumption or alcohol abstinence depending on the patients' objectives. Having a challenging background with alcohol misuse, many patients intend to remain abstinent, which may result in disliking alcohol-related cues and actively attempting to avoid them. This may be in contrast with the incentive-sensitization theory of addiction, in which alcohol-related cues acquire high motivational properties through repeated exposure, and due to over-sensitization of the dopaminergic system in the brain, the patient's attention is automatically drawn to the desired alcohol cues. The data in our study indicated that, indeed, early-stage attentional processing occurred in AUD patients, but this was followed by an active avoidance of the alcohol images, as indicated in previous research [46].

It is important to distinguish AUD patients considering their treatment trajectories from heavy drinkers and occasional social drinkers, who do not actively seek to reduce or cease alcohol consumption. The incentive-sensitization theory of addiction [10–12] may be a more prominent theoretical framework for this category of drinkers according to a study by McAteer et al. [30]. The authors found that young adults displayed a more robust AB at an early stage of attentional processing (first fixations) compared to a group of adolescents. The automaticity component of AB was seen in young adults as a result of repeated exposure to alcohol cues and having acquired incentive salience over time from adolescence to young adulthood.

On a broader clinical perspective, AB has been depicted as being one of the major components in the development or maintenance of AUD in the past decades in the field emphasizing an approach-related AB to alcohol stimuli, however, its role may be different than what previous research has promoted. For instance, a study [46] showed that patients who underwent AUD treatment displayed an avoidance AB for alcohol cues, and this AB pattern was depicted at a late attentional processing stage. In the authors' opinion, this is strongly related to the therapeutic approach of AUD, considering that AB training programs should be delivered to patients who display an approach AB for alcohol cues. A more recent study highlights that patients with severe AUD who experience significant levels of alcohol craving invested more time/interest in alcohol cues, while patients without alcohol craving showed an avoidance AB pattern [51]. These studies represent an indication that the treatment approach of AUD (e.g., AB training) should be personalized according to each individual and depending on the craving levels and the presence of an approach-related AB towards alcohol stimuli.

Nevertheless, the role of AB may be more prominent in the category of sub-clinical populations. In line with this idea, in terms of psychological assessment, AB may constitute a framework to detect subclinical drinking patterns, particularly in heavy drinkers [30]. AB training may be added as a prevention measure for individuals who display a heavy drinking pattern to reduce excessive or problematic alcohol use [52].

Unlike previous alcohol-related studies, in which the instructions revealed the overall objective of the study (e.g., attention processing), one of the common features in all three experiments was that VAT was presented to the participants as a false memory task: such strategy intended to provide a fairly stable framework of exploration of the images, therefore avoiding the fact that lengthy cognitive tasks may be linked with mental fatigue [42]. However, the impact of a false memory task on the performance of an attention-related task remains unexplored: the authors of the current research hypothesize that presenting the VAT as a false memory task may have enhanced selective attention and working memory processing as a result of the exploration strategy (intention to memorize as many elements as possible).

The major advancements of the current study are, therefore: first, the rigorous and empirically driven selection of alcohol-related and neutral stimuli by determining their salience and controlling for the technical features of the images such as brightness, contrast, and perceptual complexity in images with different composition and background; second, to design a VAT consisting of pairs of matched images with alcohol and neutral stimuli in terms of salience; third, to administer the VAT as a false memory task to all the participants; and fourth, to examine eye-movement parameters in individuals with different drinking patterns across the spectrum of alcohol consumption (from light drinking to AUD).

Limitations and Future Research Directions

The results of the current study should be interpreted in the light of its limitations. First, the sample sizes were relatively small across all experiments. In this line, post-hoc power analyses were performed for experiment 2 (concerning the results of the comparison of alcohol-related images M heavy drinkers vs. M light drinkers) and experiment 3 (based on the comparison of the mean values of the AUDIT score between both groups), displaying a power of 57.1% and 98%, respectively. Thus, whilst the power analysis performed for experiment 3 displays highly satisfactory results, the power corresponding to the experiment 2 is manifestly improvable. Second, several aspects and variables were not controlled (the attractiveness features of the images, age, gender, socio-economic or level of education, medication, potential dual diagnoses, severity of AUD, or abstinence in the clinical group of Experiment 3, for instance). Due to the timeline of the study, which was embedded in a larger project, we did not implement in the VAT previously standardized images. Although we followed rigorous steps in terms of image processing, this may be viewed as a limitation of our study. The outcomes of the study should be interpreted as preliminary results and cautiously generalized. The main focus of the study was to examine eye-movement activity using an ad-hoc VAT in samples with different drinking patterns.

Future research could focus on greater sample sizes, addressing the age-gender imbalance, and developing longitudinal rather than cross-sectional designs, with the aim of exploring and assessing attention biases. Other ET parameters, as pupillary dilation or saccades could also be explored. Moreover, implementing different technologies like ET within virtual reality systems may provide further insights regarding the dynamics of AB. The ET technology can provide important data not only on the time course of attention processing but also on how an individual explores a certain stimulus. Exploring AB toward alcohol content using eye-movement parameters may have important clinical implications at early detection of subclinical drinking patterns.

Statement of Ethics

This study protocol was reviewed and approved by the Ethics Committees at the University of Barcelona and Hospital Clinic of Barcelona in Spain [ethical code number was 0377 (HCB/2017/0377) and the approval date was 09/2017]. Written informed consent was obtained from all study participants for participation in the study.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Alexandra Ghiţă and Olga Hernández-Serrano contributed equally to this paper and they share first authorship. Conceptualization and methodology: Alexandra Ghiţă, Olga Hernández-Serrano, Manuel Moreno, and José Gutiérrez-Maldonado; software development, testing, and implementation: Alexandra Ghiţă, Olga Hernández-Serrano, Manuel Moreno, Miquel Monràs Arnau, Antoni Gual Solé, Marta Ferrer-García, Bruno Porras-García; investigation: Alexandra Ghiţă, Olga Hernández-Serrano, Manuel Moreno, Miquel Monràs Arnau, Antoni Gual Solé, Bruno Porras-García, and José Gutiérrez-Maldonado; writing, review and editing: Alexandra Ghiţă, Olga Hernández-Serrano, Manuel Moreno, Pierre Maurage, and Mariano Gacto-Sánchez. Principal Investigator: José Gutiérrez-Maldonado. All authors have read and agreed to the published version of this manuscript.

Data Availability Statement

Data are available at Harvard Dataverse https://doi.org/10.7910/DVN/XOOXPO.

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