Review

Virtual reality efficiency as exposure therapy for alcohol use: A systematic literature review

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ABSTRACT

Virtual reality is an immersive technology that can be used as a tool in the treatment of disorders linked to substance use disorders, such as alcohol use disorder. This systematic review of the literature examines the effectiveness of virtual reality as exposure therapy for heavy social drinkers, defined as people who regularly consume alcohol in a variety of social contexts, with or without a diagnosis of alcohol use disorder. The current review includes ten studies with a total of 377 participants. Most participants were adult men (61.03%), with an age average of 44.1 years [$\pm$ 7.42] and alcohol use ranging from light to heavy. Although studies show heterogeneous results, the use of virtual reality cue exposure therapies has shown greater improvement in terms of craving reduction for patients suffering from alcohol use disorder. Studies have also shown that the realism of the virtual environment can influence levels of craving and anxiety, both in heavy social drinkers. In addition, the use of virtual reality has proven to increase feeling of self-efficacy and decrease the tendency to engage in automatic drinking behaviors. However, the review also mentions the necessity of larger research to determine the efficiency of virtual reality as a therapeutic treatment for alcohol use disorder, whilst considering comorbidities and treatment background, especially for resistant patients.

1. Introduction

Alcohol is a public health issue in many cultures and has been for years (Choi and Lee, 2015). It is responsible for nearly 3.3 million deaths per year and is the 7th leading cause of premature death worldwide (World Health Organization, 2018). Despite ethanol being responsible for many harmful effects such as cognitive, psychological and physical disorders, as well as being responsible for trauma-related violence, many people find it difficult to reduce their consumption, or maintain long term abstinence Ghiţă et al., 2019a.

Craving is a key component in the development and maintenance of alcohol use behaviors in Alcohol Use Disorder (AUD) (Ghiţă and Gutiérrez-Maldonado, 2018; Bordnick et al., 2008; Bouchard et al.,

2007Bouchard and al., 2007Simon and al., 2020). It is defined as a multidimensional phenomenon, involving an intense urge to use substances or to engage in a drug-seeking behavioral pattern (Hernandez-Serrano et al., 2020; Simon et al., 2020; Bordnick et al., 2008). Craving can persist for weeks or months after alcohol cessation and constitutes a relapse factor despite a desire for a prolonged period of total abstinence. Also, anxiety, which is implicated in the predominant symptoms experienced during alcohol withdrawal, is frequent in most AUD patients. A strong causal relationship is established between anxiety and alcohol craving, making anxiety a facilitating factor in drinking behaviors and a factor in relapse (Ghiţă et al., 2019a). This relationship has fundamental implications for understanding and treating AUD, and this causal relationship between anxiety and craving acts as a

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double-edged sword. On the one hand, anxiety escalates the urgency and intensity of cravings, which significantly influences the susceptibility of individuals to succumb to these cravings, leading to continued alcohol use and potential relapse. On the other hand, this understanding provides avenues for more effective treatment and prevention strategies designed to disrupt the vicious cycle of AUD.

Treatment options for AUD include a multidimensional approach such as pharmaceutical, behavioral and psychosociological interventions (Ghiţă and Gutiérrez-Maldonado, 2018). Most relapses are triggered by cue-induced cravings/anxiety (e.g., a bar), making Cue Exposure Therapy (CET) a viable option for treating substance use disorders. CET aims to teach craving self-management techniques through in vivo, in imagination or multimedia exposure to substance-related stimuli (Ghiţă and Gutiérrez-Maldonado, 2018; Hernandez-Serrano et al., 2021). This therapy is based on classical conditioning principles; each time the signal is reinforced by a different outcome, the individual begins to let go of the associations between the signal and the previous outcomes (Trahan et al., 2019). Although CET has been very successful in treating people with phobic anxiety disorders, its effects remain limited on reducing AUD (Trahan et al., 2019). The efficacy of CET seems limited due to the ecological validity of the signals (Hernandez-Serrano et al., 2021b; Trahan et al., 2019Trahan and al., 2019). In vivo exposures are expensive and difficult to reproduce because they require specific environments and situations (e.g., a bar or nightclub), whereas CET is usually performed in laboratories (Bordnick et al., 2008; Ghiţă and Gutiérrez-Maldonado, 2018; Trahan et al., 2019). These experimental paradigms generally imply unnatural behavior associated with simple stimuli and difficulties in changing the parameters, context, and limited space available, often leading to a reduced complexity of behavioral interactions (Bordnick et al., 2008; Simon et al., 2020). Therefore, further research is needed to broaden assessment and treatment approaches.

Virtual reality (VR) has recently been investigated due to its positive factors in CET (Trahan et al., 2019). VR is "an application that allows users to navigate and interact with a three-dimensional environment created and maintained by a computer in real time" (Bouchard et al., 2007). It allows users, through a headset, to experience an intense cognitive and motor-sensory immersive experience in a computer-generated 3D universe. VR has been used in psychotherapy since the 90 s, mainly due to patients' reluctance to expose themselves to real-life violent and anxiety-ridden environments (Malbos et al., 2013). Virtual Reality Cue Exposure Therapies (VR-CET) allow the creation of a perfectly adapted hierarchy scale according to the patient's needs. Thus, the patient can progressively endure the progression of anxiety-provoking scenarios, while still having the possibility to stop the intervention at any moment. In addition to the classical paradigm, a few other variables, such as visual, auditory, olfactory, and tactile, are used. For example, for a patient who used to drink in a bar, we might start by exposing him to a street with alcohol ads, then a supermarket and finally a bar. This three-dimensional system allows for a high level of interaction, which then allows for an enhanced presence in the virtual environment (Ghiţă et al., 2019a). Studies on VR-CET have shown positive results in numerous psychopathologies, especially in anxiety disorders (Bouchard et al., 2017; Byrne et al., 2019; Ghiţă and Gutiérrez-Maldonado, 2018; Lambrey et al., 2010; Malbos et al., 2013; Park et al., 2019; Riva et al., 2019), obsessive-compulsive disorder (Laforest, 2014; Malbos et al., 2013), post-traumatic stress disorder (Ghiţă and Gutiérrez-Maldonado, 2018; Malbos et al., 2013) and addictions (Durl et al., 2018; Ghiţă and Gutiérrez-Maldonado, 2018; Malbos et al., 2013; Segawa et al., 2020; Tatnell et al., 2022; Trahan et al., 2019). Given the growing interest in this new technology, recent studies have focused specifically on alcohol. However, there appears to be no consensus on the efficacy of VR-CET as a therapeutic intervention (Trahan et al., 2019). The latest systematic reviews on the subject highlight the underutilization of VR-CET in alcohol studies (Durl et al., 2018; Segawa et al., 2020; Trahan et al., 2019). The conclusion of these reviews is that evidence for the

efficacy of VR-CET on AUD is scarce, and that the available studies have significant flaws and limitations (moderate to high risk of bias) (Durl et al., 2018; Segawa et al., 2020; Trahan et al., 2019). The most recent systematic review on the subject found no studies on the efficacy of VR-CET in alcohol studies (Tatnell et al., 2022). So, to make up for this lack of data on the subject, and in view of the rapid spread of VR, we thought it would be useful to update the data on VR-CET in alcohol studies.

2. Objectives

The aim of this systematic review of the literature is to assess the effect of VR-CET on craving, anxiety, dependence, and alcohol use. The specific question is: (i) what is the evidence of VR-CET effectiveness on reducing alcohol use, reducing craving, and reducing anxiety?

3. Methodology

3.1. Selection procedure

3.1.1. Registering protocol
The protocol for this review, was developed prior to conduct, via PROSPERO (CRD42023399302). We have followed the guidelines in accordance to the systematic review PRISMA methodology (Gedda, 2015).

3.1.2. Eligibility criteria

3.1.2.1. *Study design.* The studies selected for this review all used a randomized controlled trial (RCT) or quasi-experimental design (QED) with a control group receiving usual care, no care, waiting list or alternative care. Due to the limited number of reviews on this topic, single-group pre-post test studies were also included to provide a more detailed evaluation.

3.1.2.2. *Participants and inclusion criteria.* To differ from the latest systematic reviews on the subject (Segawa et al., 2020), we decided to extend our selection criteria to all participants who had consumed alcohol at least once in the past 12 months. Thus, the included studies considered:

- patients with a diagnosis of alcohol use disorder (AUD) recruited from the hospital setting;
- participants categorized as excessive social drinkers (HSD) without an AUD diagnosis recruited from the general population;
- participants categorized as light drinkers (LD) recruited from the general population.

For greater clarity in our article, we have decided to group AUD patients and HSD participants under the same "HSD" designation. We defined this population as people who drink alcohol regularly in a variety of social contexts and could include people with or without a diagnosis of alcohol use disorder. Age of participants was not taken into account.

3.1.2.3. *Interventions.* We only included interventions using virtual reality exposure therapy, which consists of 3D virtual scenarios that contain substance stimuli (Hone-Blanchet et al., 2014). The goal is to generate a habituation to the alcohol signals that sets a reaction, by constant exposure to alcohol linked scenarios (Trahan et al., 2019). Studies on augmented reality (i.e., defined by the addition of a virtual element to the real world that the user sees) were not included because it does not require the same hardware and it is necessary for the user to be fully immersed in the virtual environment. All other studies using associated VR-CET interventions have been included.

3.1.2.4. Outcome measurements. To be included in this review, studies had to use at least one of these standard measures: craving, anxiety, self-efficacy, alcohol dependence and/or alcohol use. The latest review of the literature on this subject highlights the need to assess dependence and maintenance of abstinence as the main evaluation criteria (Segawa et al., 2020). Consequently, particular emphasis will be placed on these criteria.

3.1.2.5. Time period and geographical context. To be included, studies had to have been published between 2012 and December of 2022, and be available in French or in English.

3.1.3. Information sources

On October, 22nd of 2022, we conducted a thorough document research on PubMed, PsycInfo, Web of Science and Sage Journals. We used the following research terms to identify the most pertinent studies: « ("virtual reality" OR "VR") AND (exposure therapy OR CBT OR cognitive behavioral therapy OR therapy OR intervention OR prevention) AND (alcoholism OR alcohol abuse OR alcohol disorder OR "alcohol*" OR alcohol dependence OR alcoholic OR alcohol addiction) ».

3.1.4. Study selection

Titles and abstracts of eligible studies were independently assessed by two reviewers (FN and MLD) via the Rayyan website to select the most relevant studies. Ineligible studies were removed, while the full text version of the eligible studies was independently assessed by FN and MLD to determine whether they were eligible according to the inclusion

criteria. Disagreements regarding the eligibility of these criteria were discussed and a third party (LR) was involved to resolve them.

4. Results

4.1. Research and study selection

After an initial search identifying 429 articles including 221 in the PubMed database, 81 in the PsycInfo database, 80 in the Web of Science database, 38 in the Sage Journals database and 9 additional references found in systematic reviews on the subject. A total of 365 articles were retained for further review and removal of duplicates. Of these, 327 were excluded because they did not meet the inclusion criteria. A total of 38 studies were retrieved for further evaluation to assess their eligibility. One study could not be retrieved in its entirety (Ryu, 2020) and 27 studies were excluded for the following reasons: wrong intervention (lack of virtual reality) (n = 4), wrong population (no alcohol) (n = 1), inadequate study design (systematic literature review, meta-analysis, protocol etc) (n = 12), wrong language (n = 1), or wrong variables (n = 9) (Fig. 1).

In the end, ten studies corresponded to the inclusion criteria and are presented in Table 1. All of them have used virtual reality as evaluation or treatment for people with alcohol use.

4.2. Selected studies characteristics

4.2.1. Studies objectives
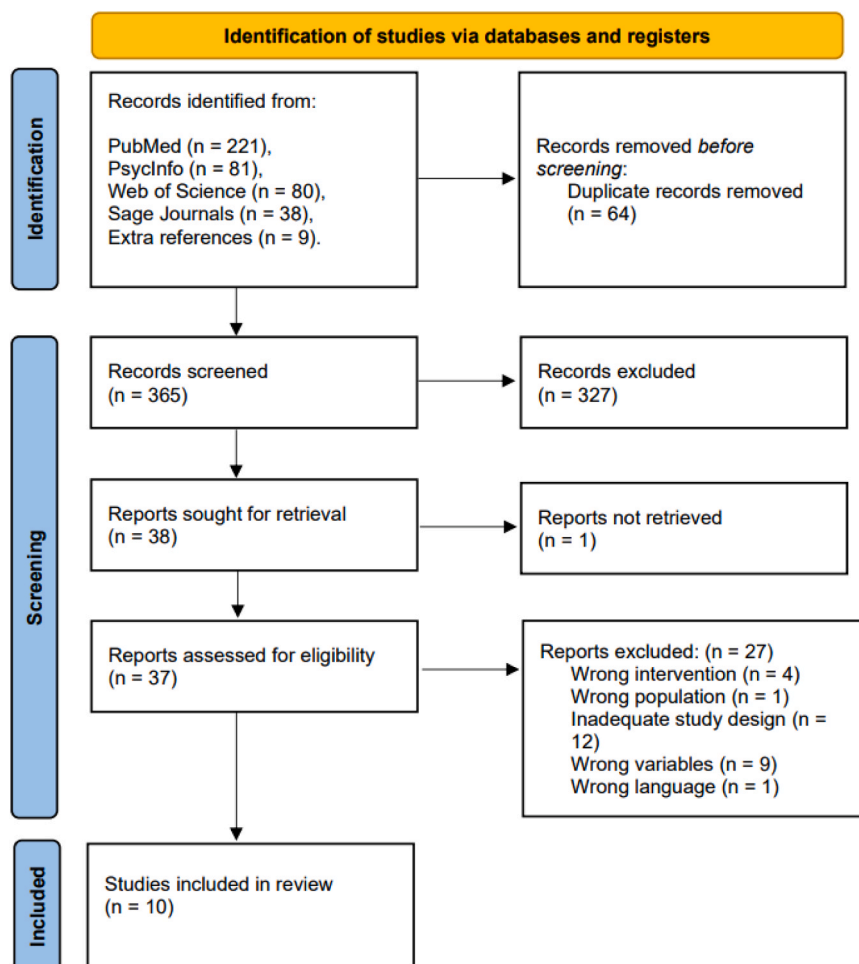The selected studies can be divided into 4 different objective groups.

Fig. 1. PRISMA flow diagram of preselection and selection process.

Table 1
Table of selected studies.

STUDIES (SORTED BY DATE)	OBJECTIVES	SAMPLE (AGE ± STANDARD DEVIATION)	TREATMENT GROUPS	PROCEDURES	INSTRUMENTS	VR ENVIRONMENTS	RESULTS
(Spagnoli et al., 2014)	Using VR as a tool to assess self-efficacy and motivation in people with AUD	N = 50 patients with AUD (age = 43.48 ± 10.88)	Experimental group (n = 25) Control group (n = 25)	Assessment of motivation and self-efficacy1 week later: SCID + RV exposure (pool, then apartment, then office, then restaurant)1 week later: assessment of motivation and self-efficacy	SCID (E, A and F modules) GSE MAC2-A	Swimming pool, Apartment, Office Restaurant.	Higher level of post-treatment self-efficacy in experimental group (F $(1,49)$ = 11,120; p = 0002) No significant difference in motivation to change
(Choi and Lee, 2015)	Reduce the craving for alcohol with secret virtual sensitization (VCS)[1]	N = 40 male students (age = N/A)	HSD with AUDIT score ≥ 12 (n=20) LD with an AUDIT score between 1 and 7 (n=20)	AUQ + alcohol-IAT + alcohol-StroopSituation VCS 10 minutes (hospital then metro)AUQ + alcohol-IAT + alcohol-Stroop	AUQ Alcohol-IAT Oculometric test (iView X™ RED-III from SensoMotoric Instruments (SMI)) Alcohol-Stroop test	Hospital, Metro.	HSDs showed a greater reduction in subjective post-treatment alcohol craving than LDs [t (18) = 5.11, p \ 0.01] HSDs showed a weaker positive association with post-treatment alcohol than that shown by LDs [t (17) = 3.84, p \.01] Participants' reaction times to alcohol-related stimuli decreased post-treatment in both groups [F (1,35) = 5.57, p \0.05,].
(Ghiţă et al., 2019b)	Testing the effectiveness of VR-CET versus CBT	N = 8 treatment-resistant patients with AUD (age = 49 ± 5.54)	VR-CET group (n = 3) CBT group (n = 5)	1 pre-treatment session with initial assessment6 sessions of CBT or VR-CET with olfactory stimuli1 post-treatment session	AUDIT MACS MACS-VR STAI VAS-C (0−100) VAS-A (0−100)	Restaurant Bar Pub Home	Significant reduction in post-treatment anxiety and craving in both groups The VR-CET group scored lower on anxiety and craving responses than the CBT group. VR-CET may be as effective as CBT in reducing craving and anxiety
(Ghiţă et al., 2019a)	Testing the effectiveness of ALCO-VR in eliciting craving and anxiety responses induced by virtual reality cues	N= 27 participants (age = 35.5 ± 5.20)	Group with AUD (n = 13) LD student group (n = 14)	Initial assessmentExposure to environments + 5 drinks with olfactory stimuli (15 minutes)Post-treatment assessmentDebriefing for the AUD group	AUDIT MACS MACS-VR STAI VAS-C (0−100) VAS-A (0−100)	Restaurant Bar Pub Home	Anxiety levels significantly higher in alcohol-related VR environments than neutral environments only in experimental group Higher levels of craving in alcohol-related VR environments than neutral environments only in experimental and control groups; Greater responses to alcohol cravings in the experimental group

Table 1 (*continued*)

STUDIES (SORTED BY DATE)	OBJECTIVES	SAMPLE (AGE ± STANDARD DEVIATION)	TREATMENT GROUPS	PROCEDURES	INSTRUMENTS	VR ENVIRONMENTS	RESULTS
(Kim and Lee, 2019)	Reducing the tendency to approach alcohol among HSD using the Virtual Alcohol Approach-Avoidance Training Task	N= 28 HSD (AUDIT score > 22) (age = 22.58 ± 2.60)	Training group (n = 14) Control group (n = 14)	VAAT Training3 sessions Implicit and explicit approach trends measured on 1er and last day	Alcohol-IAT AUDIT AUQ STAI BAS/BIS	Social events with alcohol (bar) and without (coffee) Empty room	Automatic action tendencies towards alcohol decreased in the experimental group (t(13) = 2.77, p < 0.05, Cohen's d = 0.42); Automatic action tendencies towards alcohol increased in the control group (t (13) = −4.38, p < 0.01, Cohen's d = 0.78) Craving did not decrease significantly in the experimental group [t(13) = 1,80, p = 0,10]; Craving increased in the control group simply by being exposed to alcohol-related stimuli or environments [t (13) = −2.23, p < 0.05, d of Cohen = 0.17].
(Figueras-Puigderrajols et al., 2020)	Testing the efficacy of VR-CET in patients diagnosed with AUD resistant to TAU	N = 28 patients with AUD (age = 53.82 ± 7.93)	VR-CET + TAU group (n = 12) TAU group (n = 16)	Pre-treatment session with information on abstinence and consumption, followed by an assessment TAU (+ 6 VR-CET sessions for VR-CE group with olfactory stimuli)Post-treatment session with evaluation identical to pre-treatment session	AUDIT MACS STAI Alcohol-Stroop	Restaurant Bar Pub Home	No statistically significant difference between groups (experimental vs. control) at pretreatment (STAI-Treatment (t = 1.388; p = 0.176), STAI-State (t = 1.162; p = 0.255), MACS (t = 0.076; p = 0.9396) and Stroop test (t = 0.166; p = 0,8693); No statistically significant difference between pre-treatment and post-treatment for experimental or control group; The reduction in measurements was more evident in the experimental group.
(Simon et al., 2020)	To test whether the feeling of presence mediates or moderates the relationship between past drinking experience and post-immersion craving for alcohol.	N = 39 young adults (age = 24.17 ± 2.95)	LD group (AUDIT score ≤ 7) (n = 21) HSD group (AUDIT score ≥ 11) (n = 18)	Online assessmentExposure to 4 main parts of the virtual environmentPost-treatment assessment	AUDIT VAS (1−10) ITC-SOPI UPPS-P STAI	Bar (a counter, tables, a dance floor and a gambling area. Bottles of alcohol (mainly beer) can be found in various places: several are on and behind the counter, two bottles of beer are on a table and three characters	HSD had higher craving scores than LD after immersion in a virtual environment with alcohol-related cues (t(23,96) = 2.96, p = 0007, d = 1,00); Alcohol craving is sensitive to the

Table 1 (*continued*)

STUDIES (SORTED BY DATE)	OBJECTIVES	SAMPLE (AGE ± STANDARD DEVIATION)	TREATMENT GROUPS	PROCEDURES	INSTRUMENTS	VR ENVIRONMENTS	RESULTS
						are holding a bottle of beer).	realism of the virtual environment for the HSD groups (r = 0,59, p = 0,01. Craving levels increased more strongly with the perceived realism of the virtual environment in heavy drinkers than in occasional drinkers.
(Hernandez-Serrano et al., 2020)	Determine the predictive relationship between specific variables and alcohol craving in people diagnosed with AUD	N = 42 patients with AUD (age = 54.6 ± 7.71)	VR-CET + TAU group (n = 15) TAU group (n = 27)	Pre-treatment session with information on abstinence and consumption, followed by an assessment 6 VR-CET sessions for the VR-CET group with olfactory stimuli)Post-treatment session with evaluation identical to the pre-treatment session	AUDIT MACS MACS-VR Alcohol-Stroop STAI	Restaurant Bar Pub Home	Among all participants (n = 42), more than half (52.4%) showed improvements in their initial level of alcohol craving regardless of group; The VR-CET group showed greater improvement changes in alcohol craving levels than the TAU group; In the TAU + VR-CET group, participants with intense alcohol cravings demonstrated a higher level of change, with a higher proportion improving by one and two levels.
(Hernández et al., 2021)	Identifying variables that can modulate the effectiveness of signal exposure using VR	N = 72 patients with AUD (age = 52.17 ± 8.83)	AUD group (n = 72)	Initial assessment15-minute exposure to 4 environments with olfactory stimuli Post-treatment assessmentDebriefing	AUDIT MACS MACS-VR Alcohol-Stroop STAI VAS (0−10)	Restaurant Bar Pub Home	AUD severity and perceived drink realism were predictors of cue-induced craving for alcohol; Education level, perceived realism of beverages and age were predictors of perceived realism of VR environments.
(Pennington et al., 2022)	Establish the feasibility of offering a VR-EFT exercise and intervention to a hard-to-recruit population of veterans with traumatic brain injury (TBI) and AUD	N=43 veterans with a documented history of TBI in the chronic stable phase of recovery and an AUD (age = 51.4 ± 9.40)	Exercise-Only (n=13) Gameplay Control (n=12) VR-EFT (n=18)	Pre-treatment assessment9 sessions over 3 weeks of play with exercise on tablet or exercise only1 week weaning with evaluation9 VR exercise sessions for the 2 groupsPost-treatment assessment	TLFB OCDS AUDIT BDI-II BAI NSI Neurocognitive assessments	Course-based adventure game in which the user explores an animal environment.	In the exercise-only group, participants significantly reduced the number of drinks per week during the study weeks (F (1,43) = 8.30, p = 0.006, beta [β] = −4.30; 95% CI = −7.30 to -1.30) and reported significantly less craving for alcohol (OCDS Total: F(1,10) =

Table 1 (*continued*)

STUDIES (SORTED BY DATE)	OBJECTIVES	SAMPLE (AGE ± STANDARD DEVIATION)	TREATMENT GROUPS	PROCEDURES	INSTRUMENTS	VR ENVIRONMENTS	RESULTS
							26.37, p < 0.001, beta [β] = 5.32; 95% CI = 3.03–7.62; In the exercise group, participants also reported less craving for alcohol, but only on the compulsive subscale of the OCDS (F(1,10) = 10.20, p = 0.010, beta [β] = 1.57; 95% CI = 0,48–2,67) No significant change in alcohol use or craving associated with VR-EFT condition.

[1]Covert sensitization is an imagery-based aversive treatment for decreasing craving and inducing aversion toward abused substances (Choi and Lee, 2015).
Alcohol IAT, implicit associates between alcohol and arousal; **Alcohol Stroop**, attentional bias test for alcohol-related content; **AUDIT**, alcohol use disorder identification test; **AUD**, alcohol use disorder; **AUQ**, alcohol craving questionnaire; **BAS/BIS**, behavior activation system/behavior inhibition system; **CBT**, cognitive-behavioral therapy; **BDI**, beck depression index; **BAI**, beck anxiety inventory; **GSE**, general self-efficacy scale; **HMD**, visiohelmet; **HSD**, heavy social drinkers; **IAT**, implicit association test; **ITC-SOPI**, questionnaire on feelings of immersion in virtual reality; **LD**, light drinkers; **MACS**, alcohol craving exploration test; **MACS-VR**, alcohol craving exploration test in virtual reality; **MAC2-A**, motivation for change for alcohol problems; **N/A**, not applicable/not mentioned in the text; **NSI**, post-concussion vestibular, somatic, cognitive and affective symptoms questionnaire; **OCDS**, obsessive-compulsive consumption scale; **SCID**, structured clinical interview; **STAI**, anxiety questionnaire; **TAU**: treatment as usual; **TBI**, traumatic brain injury; **TERV**, virtual reality exposure therapy; **TLFB**, consumption calendar; **UPPS**, impulsivity questionnaire; **VAAT**: virtual approach and avoidance task; **VAS**, visual analog scale; **VAS-A**, visual analog scale for anxiety; **VAS-C**, visual analog scale for craving; **VCS**, virtual covert sensitization; **VR**, virtual reality; **VR-CET**: virtual reality cue exposure therapy; **VR-EFT**: executive function training intervention (EFT) in virtual reality (VR).

Three studies aimed at using virtual reality as a VR-CET tool for AUD treatment (Figueras-Puigderrajols et al., 2020; Ghiţă et al., 2019a; Pennington et al., 2022). Within these three studies, two of them investigated the efficacy of VR-CET for the treatment of AUD (Figueras-Puigderrajols et al., 2020; Ghiţă et al., 2019a) and one study evaluated the feasibility of a protocol to offer VR-CET treatment to a population of veterans with traumatic brain injury (TBI) and AUD (Pennington et al., 2022). It is important to note that the latter is the only study to focus on reduction in use as an outcome measure. Two studies aimed to explore VR as a clinical tool in the assessment or reduction of craving (Choi and Lee, 2015) or induction (Ghiţă et al, 2019a). Two studies aimed to evaluate the efficiency of VR as an assessment tool to explore social characteristics, personality, and behaviour (Kim and Lee, 2019; Spagnoli et al., 2014). Finally, three studies aimed to explore variables that may influence the effectiveness of VR-CET on craving (Hernandez-Serrano et al., 2020; Hernandez-Serrano et al., 2021; Simon et al., 2020).

4.2.2. Sample characteristics

The ten included studies recruited a total of 377 participants (213 men, 136 women and 28 of unknown sex) with a mean age of 44.1 years [± 7.42]. Our total sample can be divided into two categories according to type of alcohol use:

1) 321 participants were classified as "heavy social drinkers" (HSD). Of this sample, 255 participants were recruited in a hospital setting and received an AUD diagnosis. The remaining participants (n=66) were students or young adults with AUDIT scores above 12, including 28 with AUDIT scores of 22 or more. An AUDIT score between 7 and 12 indicates probable excessive drinking, while a score over 12 indicates probable AUD (Saunders et al., 1993).

2) 56 participants were classified as "light drinkers" (LD) with AUDIT scores below 7 indicating a low risk of AUD diagnosis. The entire sample were students or young adults.

4.2.3. Intervention characteristics

All the studies used individual VR-CET interventions. The number of sessions varied between one (n studies=4) and 20 sessions (n study=1) (m = 5.4). They generally lasted from 30 minutes to an hour, and VR exposure time varied from 4 to 15 minutes.

4.2.4. Instrument characteristics

Most studies used the Alcohol use disorder Test (AUDIT) for diagnosis and randomization of participants (Figueras-Puigderrajols et al., 2020; Ghiţă et al., 2019b; Ghiţă e al., 2019a; Hernandez-Serrano et al., 2020; Hernandez-Serrano et al., 2021b; Pennington et al., 2022; Simon et al., 2020; Kim and Lee, 2019). A few studies used the MACS or MACS-VR in addition to the visual analogue scale (VAS) to assess alcohol need before and after the intervention. Studies that did not use the VAS instead used results from the Alcohol Urge Questionnaire (AUQ). Attentional bias for alcohol-related content has been measured using the Alcohol Stroop Test and the Alcohol Implicit Association Test (IAT-alcohol). The IAT-alcohol measures positive or negative implicit associations with alcohol. Anxiety was mainly measured with the State Trait Anxiety Inventory (STAI). Pennington et al. 2022 was the only study that used the Beck Anxiety Inventory (BAI). Only one study was interested in measuring alcohol use using standard glasses as an efficacy criterion for VR-CET, which was assessed using TimelineFollowback (TLFB) (Pennington et al., 2022). Finally, all studies used questionnaires for evaluation (e.g., alcohol urge questionnaire, anxiety questionnaire, impulse questionnaire).

a) Virtual reality environment characteristics

Five studies used the "ALCO-VR" software, which consisted of four VR environments (a restaurant, a bar, a pub and a house) and 22 alcoholic drinks, specially created to resemble real-life scenarios based on patients' experiences. The ALCO-VR software has been evaluated for its effectiveness inducing feelings of alcohol craving and anxiety, crucial emotional responses often encountered by individuals navigating AUD. ALCO-VR triggers craving and anxiety by faithfully reproducing the cues and scenarios to which individuals with different drinking behaviors (HSD and LD) would react in real-life situations. This level of specificity and differentiation is critical for personalized therapeutic approaches, helping to tailor interventions that are most relevant and effective for each category of drinker. Five studies implemented olfactory stimuli corresponding to each drink (Hernandez-Serrano et al., 2020; Hernandez-Serrano et al., 2021; Figueras-Puigderrajols et al., 2020; Ghiţă et al., 2019b; Ghiţă et al., 2019a). The different studies used the following virtual environments: bar (7), restaurant (6), pub (6), home (5), hospital (1), metro (1), swimming pool (1), office (1), empty room (1) and animal environment (1). In terms of equipment, seven studies used an Oculus headset, one used an eMagin visiohelmet and one used a Vuzix iWear visiohelmet.

A. Results of selected studies

b) Craving results

Study results indicate that VR-CET can have positive effects on reducing alcohol craving, particularly in HSD participants (Choi and Lee, 2015; Ghiţă et al., 2019b; Ghiţă et al., 2019a; Hernandez-Serrano et al., 2021; Hernandez-Serrano et al., 2020; Kim and Lee, 2019; Simon et al., 2020). Compared with other treatments, VR-CET achieved less favorable results in terms of craving reduction than the group using CBT (Ghiţă et al., 2019a; Ghiţă et al., 2019b). In Pennington et al., (2022) study, VR-CET showed no significant results on craving reduction compared with the "exercise alone" group without VR. Nevertheless, VR-CET showed greater improvement in craving levels than treatment as usual (TAU) (Hernandez-Serrano et al., 2020). The realism of the virtual environment had a significant influence on craving reduction (Hernández-Serrano et al., 2021). Indeed, when the environment is perceived as realistic, we observe a greater reduction in craving, particularly among HSD participants. Thus, the results of VR-CET's effectiveness in reducing craving seem to vary according to the type of consumption, the combination with other treatments and the nature of the virtual stimuli. Further studies are needed to better understand the underlying mechanisms and optimize the use of VR in craving reduction.

c) Anxiety results

The results suggest that VR-CET may have effects on anxiety reduction (Figueras-Puigderrajols et al., 2020; Ghiţă et al., 2019a; Ghiţă et al., 2019b). VR-CET combined with CBT showed a significant reduction in post-treatment anxiety. Nevertheless, this group performed worse than the CBT-only group on this variable. It is noted that VR-CET may be as effective as cognitive-behavioral therapy (CBT) in reducing anxiety, suggesting some similarity in effects between these two approaches (Ghiţă et al., 2019a; Ghiţă et al., 2019b). Regarding the effects of VR environments, anxiety levels were significantly higher in alcohol-related VR environments compared to neutral environments, but this seems to be observed only in HSD participants (Ghiţă et al., 2019a). The lack of pre- and post-treatment difference in anxiety in any specific study (Figueras-Puigderrajols et al., 2020) suggests that further research is needed to better understand the effects of VR-CET on anxiety, and to determine the conditions under which it may be effective.

d) Alcohol use results

In response to the limitations outlined in the last systematic literature review, there are still no articles assessing dependence and maintenance of abstinence as primary criteria. Only one study looked at reduction in alcohol use as a secondary endpoint (Pennington et al., 2022). The results of this study show that no significant change in alcohol use or craving between the 4th and 8th week of treatment was associated with the executive function training intervention in virtual reality (VR-EFT) condition as opposed to the non-VR condition. However, 20% of respondents who completed the VR-EFT condition reported that they had stopped or reduced their alcohol use after treatment. All respondents indicated that they would recommend VR exercise to others. The results indicate that intermittent technical problems, distractions from the physical environment, game speed and equipment problems may have contributed to negative aspects of the participants' experience (e.g. cyber-sickness).

e) Other results

The data indicate that VR-CET can have a positive impact on several alcohol-related aspects, such as self-efficacy, reduction of positive associations, reactivity to alcohol-related stimuli, and automatic action tendencies (Choi and Lee, 2015; Hernandez-Serrano et al., 2021; Kim and Lee, 2019; Simon et al., 2020; Spagnoli et al., 2014). Regarding personal self-efficacy, the VR-CET group showed a higher post-treatment level than the control group, suggesting that VR exposure may strengthen participants' belief in their ability to resist alcohol or change their alcohol-related behavior. Nevertheless, the studies revealed no significant difference in motivation to change (Spagnoli et al., 2014). Regarding positive associations with alcohol, HSD participants showed a lower positive association after treatment compared to LD participants. Participants' reaction time to alcohol-related stimuli decreased after treatment (Choi and Lee, 2015). Automatic action tendencies toward alcohol decreased in the VR-CET group, suggesting that VR exposure may help reduce impulsive alcohol-related behaviors. In contrast, automatic action tendencies toward alcohol increased in the control group, underscoring the beneficial potential of VR exposure compared with no treatment (Kim and Lee, 2019). AUD severity and perceived drink realism were predictors of alcohol craving, indicating that these factors influence individuals' response to VR exposure. Education level, perceived beverage realism and age were identified as predictors of perceived realism of VR environments. This suggests that these personal characteristics may influence perception of the virtual environment (Hernandez-Serrano et al., 2021).

5. Discussion

The results of this review provide preliminary support for the use of virtual reality in the treatment of people with problem drinking. Overall, studies on the efficacy of VR-CET have focused on craving, particularly its onset. According to Ghiţă et al. (2019a, 2019b)simply being exposed to alcohol-related stimuli or environments increases participants' desire to drink. Craving levels vary according to drinking type; HSD participants show higher levels of craving than LDs after immersion in the VR environment (Simon et al., 2020). In terms of craving reduction, VR-CET appears to have positive effects, particularly in HSD participants (Choi and Lee, 2015; Hernandez-Serrano et al., 2020). However, a lack of significant difference in craving and anxiety levels between pre-treatment and post-treatment for AUD patients was found in three studies (Figueras-Puigderrajols et al., 2020; Kim and Lee, 2019; Pennington et al., 2022). Although the difference between the two measurement times did not reach significance, the reduction in craving and anxiety was more evident in the VR-CET group (Figueras-Puigderrajols et al., 2020). The common feature of these studies is the choice of a complex participant sample: AUD patients resistant to TAU, veterans with TBI and HSD participants with AUDIT scores above 22 (Figueras-Puigderrajols et al., 2020; Kim and Lee, 2019; Pennington et al., 2022). More studies are needed on such complex populations.

Compared with TAU alone, VR-CET yielded better results in terms of reducing craving in HSD participants (Choi and Lee, 2015; Hernandez-Serrano et al., 2020). However, compared with other

treatments such as CBT, VR-CET showed less favorable results in terms of craving reduction (Ghiţă et al., 2019a; 2019b). These results should be interpreted with caution due to the small sample size (N=8), gender imbalance and possible confounding due to dual diagnosis.

The efficacy of VR-CET appears to be influenced by the perceived realism of the virtual environment, with a greater reduction in craving when the environment is perceived as realistic. About anxiety, VR-CET can have positive effects, but results vary. When combined with CBT, VR-CET led to a significant reduction in post-treatment anxiety, although the VR-CET group showed less favorable results than the CBT group alone. Alcohol-related VR environments were associated with increased anxiety, mainly in HSD participants.

Data are limited about alcohol use, but VR-CET showed no significant impact on short-term alcohol use (Pennington et al., 2022). More data on the longitudinal effects of VR-CET are needed to confirm or disprove its efficacy as a therapeutic instrument for reducing alcohol use. Finally, VR-CET appears to have a positive impact on other variables, including self-efficacy, reduction of positive associations, reactivity to alcohol-related stimuli and automatic action tendencies. However, the effect on motivation to change is less clear (Spagnoli et al., 2014). Dependence severity, perceived drinking reality and other individual factors have been identified as predictors of VR-CET efficacy (Hernandez-Serrano et al., 2021).

Analysis of the various reviewed studies highlights several limitations that need to be taken into consideration when assessing the effectiveness of VR-CET. Firstly, many studies were faced with a restricted sample size, which limits the generalizability of results to larger populations (Choi and Lee, 2015; Figueras-Puigderrajols et al., 2020; Hernandez-Serrano et al., 2020; Pennington et al., 2022; Spagnoli et al., 2014). In addition, some studies did not consider important multisensory aspects, such as tactile and olfactory stimulation, which could have an impact on the effectiveness of VR-CET (Spagnoli et al., 2014). Furthermore, the limited duration of treatment sessions in some studies raises questions about the durability of VR-CET's effects on alcohol craving (Choi and Lee, 2015). In addition, the use of non-clinical samples or comparisons between clinical and non-clinical samples may limit the external validity of the results (Kim and Lee, 2019). Important variables, such as socioeconomic status and ethnicity, have been overlooked in some studies, although they may influence treatment responses (Kim and Lee, 2019; Pennington et al., 2022). In addition, gender imbalances were observed in several studies, which may bias results (Ghiţă et al., 2019a; 2019b). Comorbidity with other disorders and variations in reported medications or abstinence days were also potential confounders (Figueras-Puigderrajols et al., 2020; Ghiţă et al., 2019b; Hernandez-Serrano et al., 2020). Finally, the lack of AUD-related quality-of-life measures in some studies limits the overall understanding of the impact of VR-CET on patients' lives (Pennington et al., 2022). In conclusion, despite the promising results, these limitations call for caution when interpreting the findings and underline the need for more in-depth and diversified future studies to better understand the efficacy of VR-CET in the treatment of AUD.

6. Conclusion

The dynamic world of virtual reality holds remarkable potential to transform our understanding and treatment of AUD. From its ability to trigger cravings in patients struggling with AUD to its demonstrated ability to reduce those cravings and associated anxieties in a single exposure, virtual reality has established itself as an exciting and innovative tool in our therapeutic techniques.

However, we are still at the frontier of discovery. Robust, large-scale research studies with larger, gender-balanced samples are urgently needed to further solidify these initial findings and ensure their applicability. Given the complexity of AUD, it is also critical that future research be tailored to individual patient profiles - taking into account their treatment history, comorbidities, and resistance to routine treatments.

The search to improve the effectiveness of virtual reality continues. By introducing a variety of factors, such as the perception of realism and presence or the integration of olfactory cues, we can enhance the multisensory experience and interaction within virtual environments, thereby increasing the impact of treatment.

In the midst of these advances, however, we must not lose sight of our primary therapeutic goals: maintaining abstinence or reducing alcohol use. While craving control remains critical, our approach should also directly target alcohol use reduction, an outcome that few current studies address.

As the tide of virtual reality in healthcare rises, it is crucial to rigorously evaluate and validate the efficacy and clinical relevance of these VR platforms. To this end, this paper ultimately highlights the need for comprehensive data collection and analysis. The promise of virtual reality as an adjunctive treatment in TAU for AUD patients and as a tool for alcohol use prevention and psychotherapy programs is clear. This revolutionary advance in AUD treatment is ripe for exploration - an exciting prospect for clinicians and patients alike as we navigate the uncharted waters of recovery.

CRediT authorship contribution statement

Fanny Nègre: Conceptualization, Survey, Data curation, Writing (original version), Writing (revision and editing), Follow-up, Fund acquisition; **Maud Lemercier-Dugarin:** Validation, Survey, Data curation, Revision; **Chava Kahn-Lewin:** Writing (translation); **Romain Gomet:** Revision, Fund acquisition**; El-Hadi Mohammed Zerdazi:** Revision, Fund acquisition; **Oulmann Zerhouni**: Revision; **Lucia Romo:** Validation, Data curation, Revision, Follow-up, Project management, Fund acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest.

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