Virtual Reality-Based Cognitive Bias Modification for Substance Abuse Treatment

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Bachelor Thesis

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Abstract

Background. Innovative solutions are essential to tackle rising alcohol consumption among young adults. This study assesses a virtual reality-based cognitive bias modification (VR-CBM) game designed for university students to counteract cognitive biases linked to alcohol use. **Aims.** The intervention, based on Dual Process Theory, targets both automatic and reflective cognitive processes related to alcohol consumption and examines the role of metacognitive beliefs in alcohol use behaviours. **Methods.** Eighteen university students underwent two experimental sessions. Measures included the Alcohol Use Disorders Identification Test (AUDIT), Symptom Checklist-90 (SCL-90), Approach-Avoidance Task (AAT), and Implicit Association Test (IAT), with mediation analysis to assess metacognitive impacts. **Results.** Preliminary results suggest a trend towards lower alcohol use and psychological discomfort, although limited by the small sample and lack of a control group. Metacognitive beliefs helped mediate the impact of cognitive biases on alcohol use, with significant mediation analysis findings. **Conclusions.** The VR-CBM intervention shows promise in reducing alcohol use and altering cognitive biases. It highlights how virtual reality and cognitive bias modification can enhance treatment engagement and effectiveness in addiction.

Introduction

Millions of people worldwide grapple with an abusive relationship with alcohol (World Health Organisation, 2018), posing a persistent challenge to public health systems, the quality of life, and the economy (Laramée et al., 2013). Furthermore, one of the demographics most affected by this abusive relationship with alcohol is young adults (ages 18-29), as they have the highest levels of alcohol consumption and binge drinking (Quigley & Marlatt, 1996; Ranker & Lipson, 2022). This is illustrated by their over-representation in alcohol-related traffic incidents, homicides, and suicides. Alcohol abuse is a problem that follows these young adults throughout their lives, as alcohol use in adolescence is linked to continued heavy drinking into young adulthood, with early excessive consumption often leading to alcohol-related issues later on (McCambridge et al., 2011; Brunborg et al., 2017; Enstad et al., 2019). Despite the availability of effective treatments like cognitive-behavioural therapy (CBT), the quest for more innovative and engaging interventions remains critical (Barrick & Connors, 2002). One of the reasons for this is the need for low-cost scalable solutions. Recently, the focus has shifted towards leveraging modern technology, such as Virtual Reality (VR) and gamified systems, to enhance traditional therapies (Ghiţă & Gutiérrez-Maldonado, 2018). Indeed, VR has promising applications in addiction treatment, particularly by creating immersive and controlled environments that simulate real-world scenarios relevant to addiction triggers (Mazza et al., 2021).

Reevaluating Traditional Addiction Models

Traditionally, addiction has been explained by using the brain disease model of addiction (BDMA) (Leshner, 1997). A model that posits that addictions are merely chronic brain diseases, where the brain can be hijacked by addictive substances, leading to compulsive behaviour and a loss of voluntary control. Moreover, it suggests that cue-induced responses can become habitual and that negative reinforcement driven by negative affect plays a significant role in sustaining addiction. This theory was criticised due to it not accounting for sudden recoveries from addiction, being overly dependent on animal trials, and not acknowledging psychological and environmental factors. However, it arguably takes away personal moral blame for addiction but also reduces confidence in recovery.

In contrast, recent models of addiction such as the systems perspective model by Wiers & Verschure (2021), states that addiction is a complex phenomenon influenced by various factors beyond just individual behaviours or brain abnormalities. The systems perspective model emphasises the complexity of addiction, highlighting the need to consider the physical and social environment in treatment in addition to the neuronal mechanisms involved. VR technology emerges as a promising tool in this context. VR's immersive nature allows for the creation of controlled and dynamic environments that simulate real-world scenarios and social cues relevant to addiction triggers, directly addressing this multi-scale organisation of addiction. It provides opportunities for individuals to engage both reactive and cognitive control systems following the dual-process theory while practising new, deliberate responses to addiction-related triggers, overcoming unconscious biases while becoming more aware of and mitigating automatic reactions. These arguments point towards VR-based interventions potentially contributing to lasting behavioural changes.

Dual Process Theory: A Framework for Understanding Addiction.

A central, well-established theoretical framework to consider in the context of treating alcohol addiction is the so-called Dual Process theory or Dual System theory. This framework, which traces its roots to psychology pioneers such as William James and has been further developed by Gazzaniga and Nobel laureate Daniel Kahneman, stipulates that our thought process can be divided into two distinct systems (Kahneman, 2011). In Kahneman's view, System One is fast, intuitive, impulsive, and reflexive. In contrast, System Two is slower, more deliberate, and methodical, aligning with controlled processing, as further described by Schneider and Chein (2008). This system engages in thoughtful processing and metacognition, which relates to our awareness and executive control of behavioural processes (Schraw, 1998). System Two includes functions such as actively assessing and adjusting our cognitive processes to recognize and reduce automatic reactions, inhibiting automatic responses, and shifting our attention when necessary (Miyake et al., 2000). The Dual-process theory has been shown to be of great relevance in the treatment of addiction (Stacy & Wiers, 2010). According to the Dual-process theory, System 2 thinking encompasses a wide range of conscious beliefs and preferences, including both implicit and explicit attitudes towards substances like alcohol (Stacy & Wiers, 2010). However, metacognitive beliefs, as defined in the context of alcohol use, represent a specific subset of these reflective cognitions.These metacognitive beliefs reflect a self-referential thought concerning the use of alcohol to manage cognitive and emotional states (Spada & Wells, 2008). This differentiates metacognitive beliefs from the broader array of cognitions captured under System 2, as they specifically relate to one's awareness and management of cognitive processes, thereby playing a unique role in the maintenance of addictive behaviours. Additionally, Gierski et al. (2015) have demonstrated that metacognitive beliefs correlate with alcohol use patterns among university students.

The Interplay of Cognitive Systems in Substance Abuse.

Understanding the connection between reactive system One and deliberative system Two is crucial in addiction treatment (Bechara et al., 2000). System One's automatic responses can trigger addictive behaviours in response to environmental cues. At the same time, System Two's reflective capabilities are essential for recognising harmful patterns and consciously striving to inhibit and change them. This dual-system perspective creates opportunities for addressing the multifaceted nature of addiction by underscoring the importance of both recognising impulsive reactions and mitigating them. Moreover, these two systems might be bi-directionally coupled. For instance, a study conducted by Herreros et al. (2019) on chronic cannabis users shows that substance abuse can boost System One’s automatic responses and so impair the brain's cognitive control systems, and so might impair System Two's reflective abilities. This suggests an intricate and complex interplay where addiction not only triggers impulsive behaviours but is also able to hamper the capacity for deliberate decision-making and acquiring new rewarding strategies, which is crucial for effective addiction treatment such as in Cognitive Bias Modification (CBM) therapy.

Cognitive Bias Modification

CBM represents a set of therapeutic interventions designed to directly alter problematic cognitive biases which are believed to contribute to various psychological disorders, including addiction. Cristea et al. (2016) define CBM as the purposeful alteration of a specific cognitive bias through prolonged exposure to task conditions that promote preferred cognitive processing patterns. In this case, CBM aims to reduce the automaticity of maladaptive attentional, interpretative, and action tendencies toward addiction-related stimuli. The underlying premise of CBM, based on dual-process theories, posits that these automatic processes are pivotal in maintaining addictive behaviours and are relatively resistant to change through traditional interventions. CBM techniques, such as those targeting attention biases or approach biases, are designed to recalibrate these automatic tendencies, thereby influencing not only the biases themselves but also the broader neurocognitive mechanisms underlying addiction. For example, Wiers et al. (2015) found that CBM targeting approach biases towards alcohol cues, reduced craving rates by impacting cue reactivity in brain regions associated with reward processing.

Refining CBM

The ABC model, as proposed by Wiers et al. (2020), builds on the fundamental ideas of CBM and refines the strategy by organising the intervention around the hierarchy of Antecedents, Behaviours, and Consequences. This methodical approach is believed to be essential for teaching people how to actively change their attitudes and responses, or behaviours, in the present, as well as how to identify the triggers, or antecedents, that lead to substance use. The model's emphasis on comprehending the results (Consequences) of changed behaviours is vital since it promotes learning through feedback and makes behaviour modification tracktable. Through the identification of these components, the ABC model augments the ecological validity of CBM, hence making the intervention more practically relevant to conditions encountered by individuals grappling with addiction.

In practical terms, the ABC model is implemented in this study by simulating complex social interactions where participants face common addiction related triggers (Antecedents) in VR environments. Following this, participants are instructed to use different actions (Behaviours) in reaction to these triggers, and the VR system gives them instant feedback

(Consequences) on the results of their choices. By providing participants with quick feedback, the CBM process is grounded in observable, achievable results and helps participants grasp the direct consequences of their actions.

This project shows that, the ABC paradigm can be enhanced and its ecological validity improved, by the use of contemporary technologies such as VR, which offers a dynamic platform that not only replicates the intricacy of real-world interactions but also facilitates the practice and reinforcement of these novel behavioural strategies in a realistic but controlled environment (Ghiţă and Gutiérrez-Maldonado, 2018).

Behavioural and Cognitive Biases and their Impact on Addiction

There is an extensive body of research focusing on retraining biases central to addiction (Field et al., 2016; Cousijn et al., 2011). This includes Approach Avoidance Bias (AAB), defined as the tendency to automatically approach cues related to a specific behaviour and avoid cues related to the opposite of that behaviour (Watson et al., 2013). This AAB bias is generally measured using Approach Avoidance Tasks (AAT), tools designed to measure these automatic tendencies. For example, in one example task, participants are presented with images related to alcohol on a computer screen and are instructed to pull a joystick toward themselves (approach) when they see a non-alcoholic beverage image and to push the joystick away (avoid) when they see an alcoholic beverage image (Wiers et al., 2010). Hence, the AAB paradigm has potential to be translated into experimental protocols ready for implementation using computer game technology such as VR. Secondly, Attentional Bias (AB), which is the tendency to pay more attention to specific cues rather than neutral cues in the environment (Williams et al., 1996), or in this case, pay more attention to alcohol-related cues rather than non-alcohol-related cues. AB is measured using Implicit Attentional Tasks (IAT), tools used to measure attentional tendencies. For example, a participant might be shown images or words related to alcohol and asked to quickly categorise these along with positive words or negative words. The speed of their responses can reveal implicit biases, indicating instinctive associations of alcohol with either positive or negative attributes (Cox et al., 2006).

Virtual Reality and Gamification: Frontiers in Addiction Therapy

Research on Video games and gamification demonstrates that they can provide an effective medium for training and rehabilitation. Video games span a range of genres and platforms and engage players in environments that challenge their psychological, cognitive, and behavioural skills. Recent advancements in this domain have highlighted video games' potential in therapeutic settings, particularly in cognitive rehabilitation and modification therapies (Ramos-Galarza et al., 2024). This approach leverages the engaging and immersive nature of video games to facilitate the modification of cognitive biases, such as the approach-avoidance bias, which is prevalent in substance addiction disorders as described above. Gamification, or the use of game design elements such as Narrative, Reinforcement, and Role-play (Green & Brock, 2000; Biddle & Thomas, 1979), Sensory Immersion (Lombard & Ditton, 2006; King, 1993), Interactivity and Agency (Ryan & Deci, 2000), and Feedback (Skinner, 1963; Beck, 1979) in non-game contexts (Kapp, 2012), such as therapeutic exercises within a VR framework provides a intriguing avenue for therapy, offering a dynamic and interactive environment where users can actively engage in treatment processes (Ghiţă & Gutiérrez-Maldonado, 2018). The combination of video game technology and psychological intervention holds promise for developing more effective treatments for alcohol addiction and other substance abuse disorders, potentially leading to lower relapse rates and improved patient outcomes.

In their 2015 study, Boendermaker et al. explored the integration of gamified elements into CBM specifically targeted at adolescents with substance use issues. Unlike conventional CBM sessions, which may not fully engage a younger audience and can be costly due to the necessity of therapist-led sessions, their approach incorporated serious gaming elements directly into CBM tasks. This adaptation was designed to enhance intrinsic motivation and presented a potentially more cost-effective method by reducing reliance on therapist-led interactions. However, it is important to acknowledge that while this study was pioneering in combining CBM with gamification, the levels of engagement achieved did not yet parallel those of commercial video games. This discrepancy underscores an ongoing challenge in making therapeutic games as engaging as their purely entertainment-based counterparts. Furthermore, the effectiveness of this gamified CBM approach was not conclusively established in their initial research requiring more study. Yet, the application of gamification within CBM presents a compelling opportunity to boost engagement among adolescents, a demographic often difficult to reach through traditional therapeutic means. This project aims to contribute to this goal.

Boendermaker et al. (2015) provide several recommendations for future research and application in this field. They caution that the term 'game' should be used carefully to manage expectations about the fun and engagement level of serious games designed for health interventions. For instance, they suggest that aligning game elements with therapy goals should occur without imposing additional cognitive loads that could detract from therapeutic efficacy. They also highlight the need to balance intrinsic and extrinsic motivations within game protocols. While extrinsic rewards such as points and levels can increase engagement, the core mechanics of the interaction and experience must support therapeutic objectives effectively. Finally, game elements should be tailored to fit the intended duration and intensity of therapy sessions to ensure that gamification not only increases the frequency of engagement but also enhances the quality and effectiveness of the intervention.

Current Research

This study investigates how gamified VR systems might be used to recognise and modify detrimental cognitive processes linked to alcohol abuse. The study explores whether combining therapy sessions with entertaining game mechanics and cutting-edge VR technology can enhance patient engagement and result in long-lasting behavioural improvements. This research focuses on using the intuitive, impulsive System One of the brain to retrain cognitive biases while simultaneously using the reflective, deliberative System Two of the brain, based on the Dual Process Theory and the Systems Approach Model. The purpose of this dual-system engagement is to improve metacognitive skills, which enable people to identify and change their instinctive prejudices. The main goal is to ascertain if VR-based therapies can improve dual-process control over decisions and behaviours associated with addiction.

This thesis details the development and evaluation of a VR game designed to implement the AAB protocol and assess whether it reduces excessive alcohol consumption among university students, who may be at high risk but not necessarily addicted. The VR game developed in this project draws inspiration from environments seen in popular role-playing video games and covers two sessions. It blends missions targeting biases in alcohol consumption with engaging activities that extend beyond the direct therapeutic content, aiming to create a captivating, immersive experience with significant potential for behavioural and cognitive modification.

The primary objective of this study is to assess the impact of a VR-based gamified intervention for modifying cognitive biases associated with alcohol use. The intervention focuses on the modification of approach-avoidance and attentional biases. The target group is university students who are heavy drinkers. The central research question is: Does participation in a VR-based gamified CBM intervention lead to a decrease in approach-avoidance and attentional biases toward alcohol among university students, leading to a decrease in alcohol consumption? This effect will be measured through the Approach-Avoidance Task (AAT), and Implicit Association Test (IAT). The project hypothesises that the intervention will significantly reduce implicit biases towards alcohol that will correlate with a decrease in alcohol consumption levels.

This study's secondary objective is to investigate whether modifying impulsive responses via gamified CBM-based VR elements that include both automatic and deliberative task components can enhance controlled, cognitive processes related to alcohol consumption. The secondary research question being; Can the gamified VR intervention facilitate metacognition and in turn modify cognitive biases in addition to changing alcohol-related behaviours? It is hypothesised that the intervention will not only reduce automatic, impulsive responses to alcohol cues (as measured by reduced approach-avoidance and attentional biases) but will also enhance the engagement of reflective, deliberative processes. This enhancement is expected to mediate the relationship between changes in cognitive biases and reductions in alcohol use.

To test this hypothesis, a mediation analysis will be performed to evaluate whether increases in deliberative engagements (measured through task-specific assessments of reflective decision-making within the VR environment) act as mediators between the reduction in cognitive biases and the decrease in alcohol consumption levels. This analysis will help clarify how elements aimed at deliberation contribute to the intervention’s effectiveness and provide a comprehensive understanding of the intervention's impact on both automatic and reflective cognitive processes.

Methods

Design

Type of Research and Variables. The experimental design of this study assess the efficacy of Cognitive Bias Modification (CBM) in altering alcohol-related behaviours using a within subject analysis.

Independent and Dependent Variables. The primary independent variable (IV) is the participants' exposure to the VR-CBM game, across two sessions: day one and day two. This arrangement allows us to assess immediate cognitive changes and broader behavioural effects over time.

The dependent variables (DVs) include D-Scores for the Approach-Avoidance Task (AAT) and the Implicit Association Test (IAT), which measure shifts in cognitive biases. Additionally, it also includes scores from several psychological questionnaires, including the Alcohol Use Disorders Identification Test (AUDIT), which evaluates alcohol consumption patterns; the Symptom Checklist-90 (SCL-90), which provides a comprehensive measure of psychological distress; and the Positive and Negative Alcohol Metacognitions Scales (PAMS/NAMS), which assess metacognitive beliefs about alcohol use. These measures collectively provide insights into cognitive biases, and psychological distress related to substance use.

Participants

Initially, the groups targeted in this study were female university students who consume eight standard units of alcohol per week and male university students who consume 13 standard units of alcohol per week. After seeing that a large number of possible participants were unsure about their weekly consumption, all students were admitted. A sample size of n = 20 was gathered. This sample was strictly used as the experimental group, who will use the VR-CBM game. Due to a lack of participants and time, the control group was omitted.

The participants were collected via the researcher's social circle, snowball sampling, and the University of Twente's internal research participation system called SONA, where students in the experimental condition were offered 4.5 ECs (European Credits) in exchange for their participation.

Materials

The study utilised a comprehensive set of tools and software to facilitate the assessment and intervention components of the research. Participants interacted with the game through the Oculus/Meta Quest 2 VR headset, providing an immersive experience for the CBM tasks. A laptop with an internet connection supported data collection and task administration, using Inquisit 6 software to administer the Implicit Association Test (IAT) and the Approach-Avoidance Task (AAT).

Implicit Association Test (IAT). The IAT measures implicit preferences by assessing reaction times in sorting tasks. Using predetermined keys, participants classify terms and visuals that are associated with "good" or "bad," as well as "alcohol" or "sodas." This test employs practice rounds and test blocks with alternating category pairings to investigate biases. With a duration of roughly 5.5 minutes, the D-score indicates the intensity of these biases towards hypothesis-consistent or inconsistent pairings.

Approach-Avoidance Task (AAT). The AAT uses keyboard responses to evaluate implicit behavioural tendencies towards certain stimuli. Participants classify photos as either landscape or portrait in this exercise. Pressing the 'T' key shrinks landscape visuals, signifying avoidance, and pressing the 'B' key enlarges portrait images, signifying approach. This method assesses the automatic inclinations to approach or avoid stimuli that are shown, such as soda or alcohol, which are indicative of underlying emotional and cognitive processes. The brief, about six-minute AAT process analyses answer accuracy and speed to yield valuable information on participant biases.

Alcohol Use Disorders Identification Test (AUDIT). The AUDIT was developed by the World Health Organization, and was used to assess alcohol consumption patterns and related behaviours. This 10-question screening tool has a total score ranging from 0 to 40, with a score range of zero indicating abstention, from one to seven suggesting low-risk consumption, eight to 14 indicating hazardous or harmful alcohol use, and 15 or higher pointing to probable alcohol dependence. This globally recognised tool effectively identifies individuals at various levels of risk (Saunders et al., 1993), and additionally, its consistent psychometric properties make it effective in identifying individuals at different risk levels in diverse cultural contexts (Reinert & Allen, 2007).

Symptom Checklist-90 (SCL-90). Psychological symptoms and psychopathology were evaluated using the SCL-90, which offers a comprehensive measure of psychological distress through its 90 items.

Positive and Negative Alcohol Metacognitions Scales. Additionally, metacognitive beliefs about alcohol were assessed using the Positive and Negative Alcohol Metacognitions Scales (PAMS and NAMS); PAMS consists of nine items, and NAMS comprises six items, exploring beliefs about the cognitive and emotional benefits and the potential uncontrollability and negative consequences of alcohol use, respectively.

Data analysis was performed in "R Studio" using packages such as "dplyr" for data manipulation, "ggplot2" for creating visualisations, "wesanderson" graphics package colour palette "GrandBudapest2" for optimal visibility of the plots, "lme4" for fitting linear mixed-effects models, and "lavaan" for the mediation analysis, allowing for a robust evaluation of the collected data.

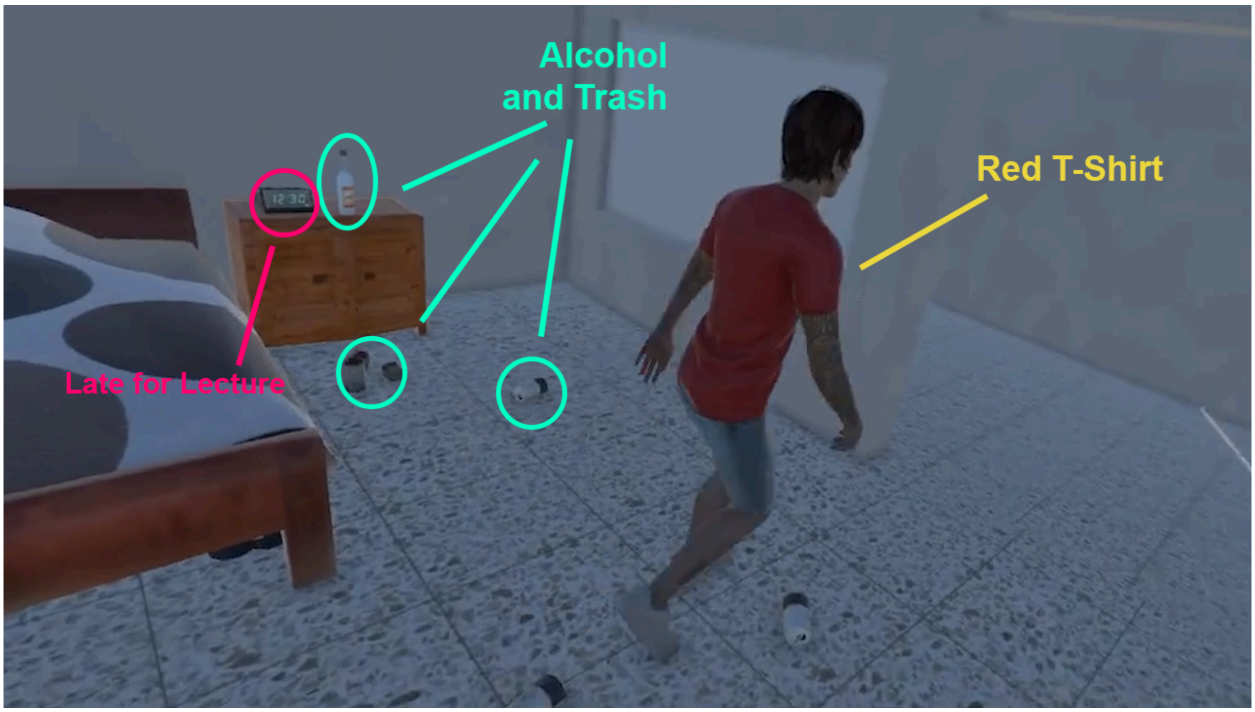
Integrated Game Design for Cognitive Bias Modification. The VR game was made in Unity 2022.3.19f1, using the XR Interaction Toolkit as the primary foundation. Assets were either made in-house or taken from "Sketchfab". The narrative centres on Alex, a 22-year-old psychology student navigating daily challenges and decision-making related to alcohol exposure over two consecutive days.

Gameplay and CBM Techniques.

Day One- Wake up scene. Day One starts with Alex feeling bad and realising he will be late for his lecture. The room is extremely messy, filled with empty beer cans and alcohol bottles (Figure 1).

Figure 1

Day One Wake Up scene



This scene uses dialogue and visual cues to highlight the negative consequences of excessive drinking. While we cannot be entirely sure that these implicit visual messages effectively engage the participant's System 2, our intention is to encourage reflective thinking about the long-term impacts of excessive alcohol consumption.

Day One- Lecture level. After leaving their house and entering the lecture, participants must pay attention and categorise each stimulus shown on the screen as alcoholic or non-alcoholic while counting the number of stimuli presented (Figure 2, Image A). Participants are shown five alcoholic and five non-alcoholic stimuli, making for a total of 10 stimuli. In order to mimic a regular classroom environment, during the lecture, they must also remain focused while ignoring various environmental distractions, such as incoming messages or conversations among their peers. This aims at training executive control abilities rather than retraining attentional bias. The categorization uses two buttons: green for non-alcoholic stimuli and red for alcoholic stimuli (Figure 2, Image A).

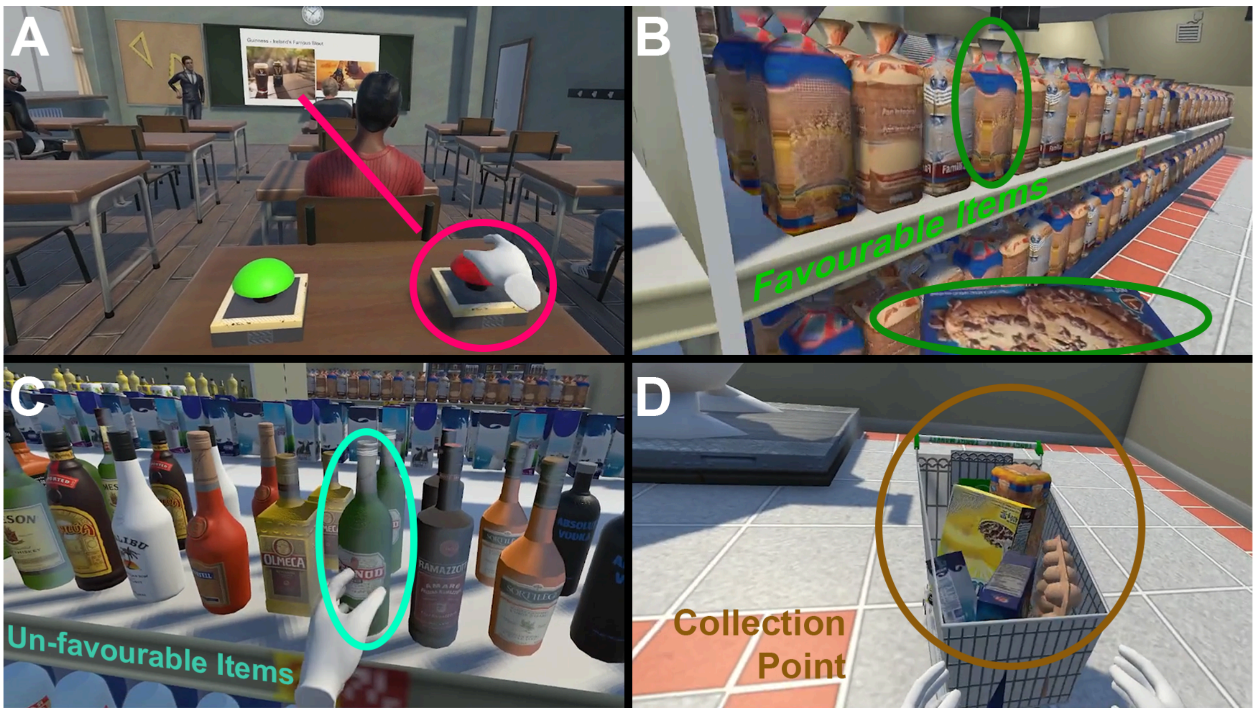
Participants are shown five alcoholic and five non-alcoholic stimuli. The use of colour-coded buttons leverages the natural associations people have with these colours (green as positive/excellent and red as negative/bad) (Mammarella et al., 2016) and therefore makes categorization more intuitive, rapid, and automatic in order to leverage the user's bias towards either stimulus. Additionally, by consistently associating non-alcoholic stimuli with a positive colour (green) and alcoholic stimuli with a negative colour (red), the task helps participants develop a bias towards avoiding alcoholic stimuli through evaluative conditioning. The task includes gamification features such as feedback, where correct responses trigger a positive sound, and incorrect responses trigger an error noise. If participants fail the questions, they must repeat the task, encouraging proficiency through repetition and reinforcement learning.

Additionally, the lecturer engages in excessive sharing of personal trauma, sharing personal stories about how alcohol has negatively affected his life, including a divorce, estrangement from his daughter, and financial troubles. These stories aim to highlight the severe consequences of alcohol abuse, further engaging the participant's metacognitive System 2 by creating a reflective and emotional understanding of alcohol's impact. Although this approach is intended to foster reflection, it should be noted that the effectiveness of this method in engaging

System 2 is based on the assumption that emotional and personal narratives can enhance reflective processing (Green & Brock, 2000).

Figure 2

Day One Lecture and Supermarket levels



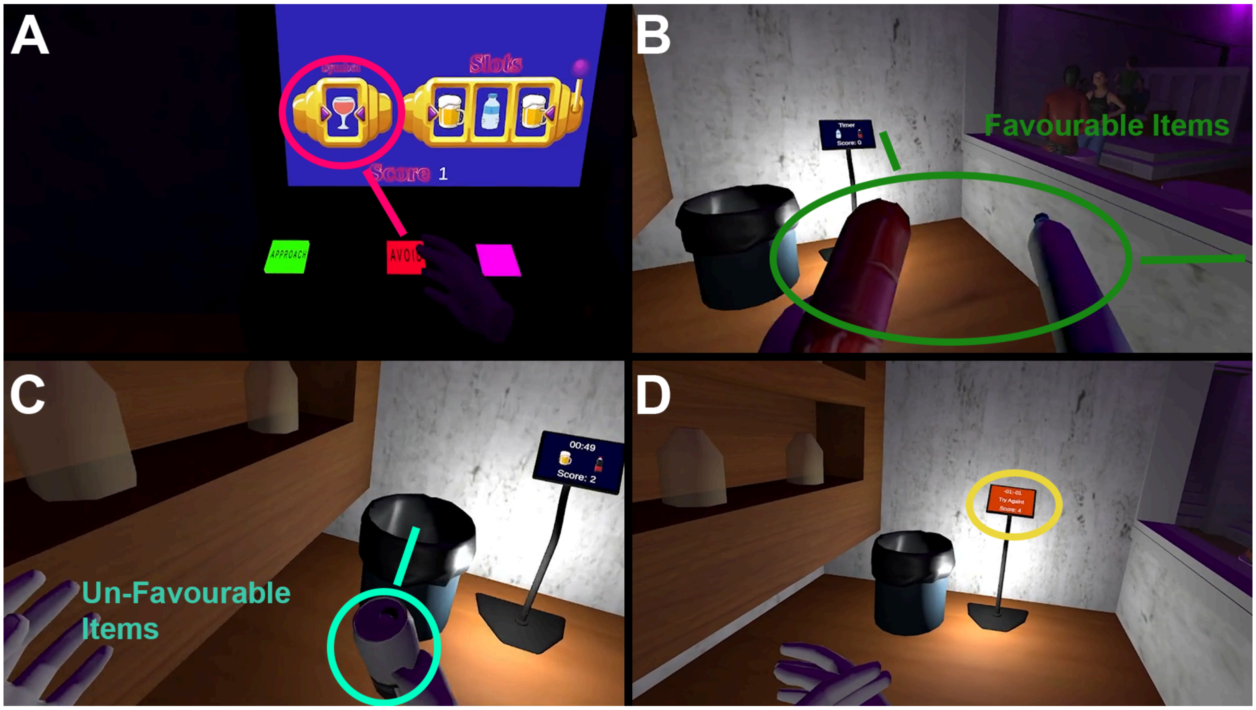
Day One- Supermarket level. Consequently, the user is put in a supermarket environment (Figure 2, Images B, C, and D), where the participants must collect five non-alcoholic items (bread, eggs, cookies, milk, and cereal) amidst a balanced mix of alcoholic and non-alcoholic options (approximately 50/50). The supermarket is filled with a variety of products, with an overall balance of 50% non-alcoholic items and 50% alcoholic items. This involves approach-avoidance training, where participants practise avoiding alcoholic items amidst increased temptation, reinforcing healthier decision-making. The task also strengthens the intention to avoid alcohol by repeatedly making decisions to select non-alcoholic items.

The supermarket level includes gamification features such as feedback. For example, the level restarts if an alcoholic drink is put in the shopping cart. This immediate feedback mechanism reinforces correct behaviour and encourages participants to avoid mistakes.

Day One- Bar Level - Slot Machine. The next level is set in a bar environment. The first task involves a slot machine (Figure 3, Image A). The user is set with three buttons: a purple button which spins the first reel, also called the symbol reel, and a red and green button marked with approach and avoid. The user must click the green or red button based on the stimuli they got on the symbol reel (Figure 3, Image A).

Figure 3

Day One Bar levels- Slot machine and Bartending



After selecting either approach or avoid, the next three reel spins, regardless of the symbols they get, this last reel spin does not provide or remove any points. Participants must reach 10 points, with each correct approach to water earning 2 points and each correct avoidance of alcohol earning 1 point. Mistakes result in point deductions. This slot machine task involves making quick decisions to approach or avoid symbols based on their association with alcohol, a technique that trains participants to avoid alcohol-related cues automatically. Positive reinforcement is provided by successfully avoiding alcohol-related symbols and selecting non-alcoholic ones, which gives immediate feedback and encourages continued avoidance of alcohol. The task includes gamification features such as scoring points for correct responses and deducting points for mistakes. Participants must reach 10 points to complete the task, incentivising correct responses.

Day One- Bar Level - Bartending. Following the slot machine task, day one concludes with the bartending task (Figure 3, Images B, C and D). This task requires participants to serve only non-alcoholic beverages and throw any alcoholic beverages that customers order into the trash can (Figure 3, Images B and C). Each order has two drinks (Figure 3, Image B), and participants must complete five orders to earn five points, encountering at least 10 stimuli.

This task involves AAB training, reinforcing the ability to discriminate between alcoholic and non-alcoholic options. Participants practise serving non-alcoholic beverages in a simulated environment, which helps them rehearse and solidify these behaviours, making them more likely to replicate them in real-life situations . Throwing alcoholic beverages into the trash can (Figure 3, Image C) acts as a form of positive reinforcement by rewarding the participant's behaviour of avoiding alcohol-related cues and choosing to discard alcoholic drinks.

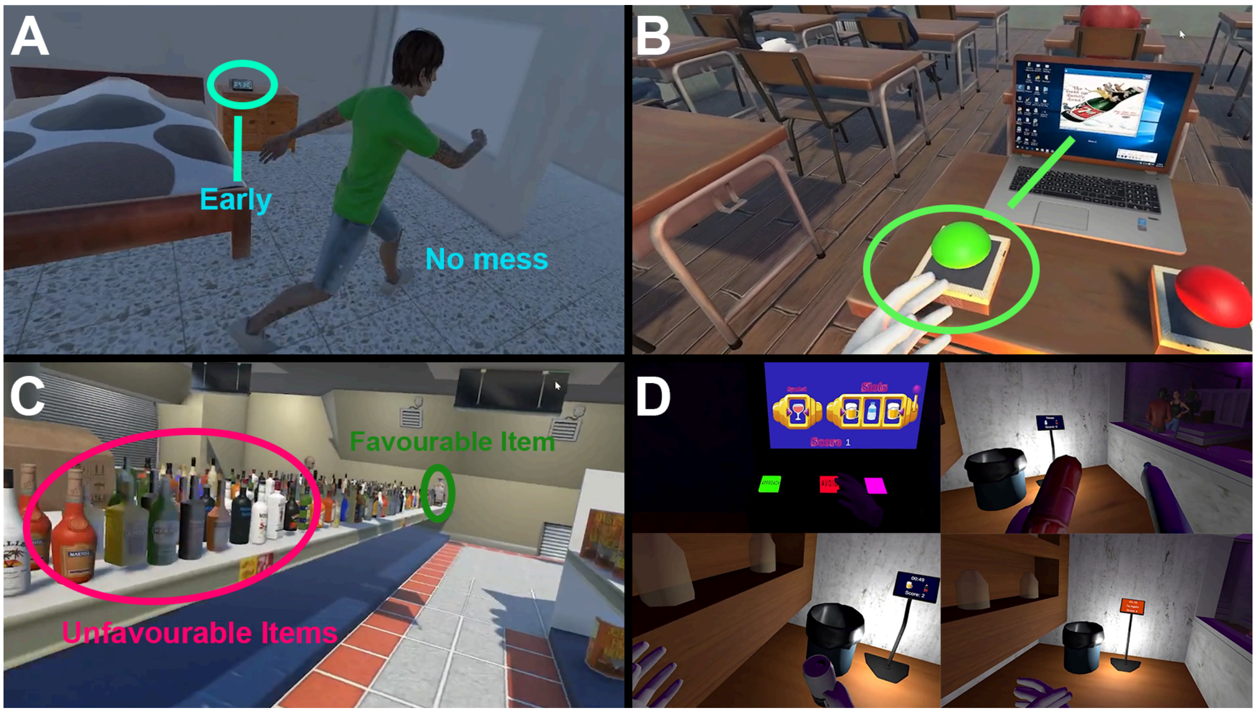
The bartending task includes gamification features such as timing, where participants have 1 minute to complete two orders, adding a sense of urgency and challenge (Figure 3, Image D). Points are deducted for putting the wrong stimulus in the wrong drop-off zone (e.g., beer in the bar drop-off zone or non-alcoholic drinks in the trash can). If participants run out of time, they must start the task again, reinforcing the need for quick and accurate responses.

Additionally, the task is introduced with the narrative that the regular bartender has blacked out due to excessive drinking, highlighting the severe consequences of alcohol misuse. This serves to engage the participant's metacognitive System 2, fostering reflective thinking about the long-term effects of alcohol abuse.

Day Two- Wake up scene. Day Two starts with a clear-headed Alex, depicted in a tidy room with no signs of alcohol consumption (Figure 4, Image A). This scene visually contrasts the previous day's wake-up scene, aiming to reinforce the positive outcomes of abstaining from alcohol (Figure 1; Figure 3, Image A).

Figure 4

Day Two levels



Day Two- Study session level. Participants continue to discriminate between alcoholic and non-alcoholic stimuli in a university study session. The user is seated in front of a computer display, where different stimuli appear on the screen (Figure 4, Image B). As before, they must press the appropriate buttons (green for non-alcoholic, red for alcoholic).

The session includes auditory feedback, with positive sounds for correct responses and error noises for incorrect ones. Participants must reach 20 points, encountering 10 alcoholic and 10 non-alcoholic stimuli. This task uses CBM by utilising colour-coded buttons to influence automatic cognitive processes. The consistent association of non-alcoholic stimuli with positive cues and alcoholic stimuli with negative cues reinforces AAB training. Gamification features include feedback, with correct responses triggering a positive sound and incorrect responses triggering an error noise. Participants must reach 20 points to complete the task, providing a clear goal and incentive. If participants fail to answer correctly, they must restart the task.

Day Two- Supermarket level. Participants are placed in the supermarket environment again, but with higher levels of alcoholic stimuli to avoid (approximately 90% alcoholic, 10% non-alcoholic) (Figure 2, Image B; Figure 4, Image C).

They must again collect five non-alcoholic items (bread, eggs, cookies, milk, and cereal). This task involves approach-avoidance training, practising avoidance of alcoholic items amidst increased temptation, and reinforcing healthier decision-making. It also strengthens the intention to avoid alcohol by repeatedly making decisions to select non-alcoholic items. The supermarket level includes gamification features such as feedback, where the level restarts if an alcoholic drink is put in the shopping cart.

Day Two- Bar Level. Day two culminates in the bar scenario again, with the slot machine and bartending tasks following suit as in day one (Figure 4, Image D).

Procedure

The study started with the recruitment of participants, who first read the information and provide informed consent after any questions they might have are addressed. All participants start by filling out a comprehensive initial questionnaire assessing various psychological and behavioural dimensions related to alcohol use. This includes the AUDIT, the SCL-90 and both the PAMS and NAMS.

Following the questionnaire, participants undergo the Implicit Association Test (IAT) to evaluate implicit biases towards alcohol and the Approach-Avoidance Task (AAT) to assess changes in their reactions to alcohol-related stimuli. Participants subsequently engage with the game on day one. They are invited to return the next day, or at most two days later, to continue with day two of the game. Day two of the intervention mirrors the procedure for day one, where instead of playing the game last, they start the session playing the game. Post-game, participants complete another round of the IAT, followed by the AAT. The session concludes with the participants filling out the same set of questionnaires to identify any shifts in their attitudes, beliefs, and behaviours regarding alcohol use.

Data Analysis

This section outlines the statistical analyses conducted to address the research questions and test the study's hypotheses. Data from various sources, including the Implicit Association Test (IAT), Approach-Avoidance Task (AAT), Alcohol Use Disorders Identification Test (AUDIT), Symptom Checklist-90 (SCL-90), and the Positive and Negative Alcohol Metacognitions Scales (PAMS and NAMS), were analysed using a combination of descriptive, inferential, and advanced statistical techniques. Initially, the data underwent thorough cleaning and preprocessing to ensure completeness and consistency, with any missing data addressed appropriately.

Primary analyses included conducting paired t-tests to compare mean scores across phases or sessions (Pre and Post) for each test, providing insight into any significant changes due to the intervention.

For the Implicit Association Test (IAT), the D-Score was calculated to reflect the strength of automatic associations between concepts. The D-Score is the standardised mean difference score between 'hypothesis-inconsistent' pairings and 'hypothesis-consistent' pairings. Positive D-Scores indicate a stronger association between 'Alcohol-Positive' and 'Sodas-Negative' than the opposite pairings, while negative D-Scores suggest a stronger association between 'Sodas-Positive' and 'Alcohol-Negative'. This measure is based on the improved scoring algorithm by Greenwald et al. (2003), which handles error trials by requiring corrections and calculates the D-Score as the average of the scores from different test blocks.

For the Approach-Avoidance Task (AAT), response times to alcohol-related stimuli were measured to assess implicit behavioural tendencies towards avoidance or approach. We calculated the median response times for correct trials, from which D-Scores were derived by subtracting the median latency of pull trials from push trials specifically for alcohol-related stimuli and dividing by the individual standard deviations. In the Approach-Avoidance Task, positive D-Scores indicate faster responses when pulling towards (approaching) alcohol-related cues compared to pushing them away (avoiding), suggesting a tendency towards approaching alcohol. Conversely, negative D-Scores demonstrate faster responses when pushing away (avoiding) compared to pulling towards, indicating a stronger tendency to avoid alcohol-related cues. Additionally, scores near zero are considered neutral, reflecting no strong implicit bias towards or against the stimuli, suggesting a balanced reaction without a clear preference for avoidance or approach. These scores are important indicators of the participants' implicit reactions.

Standardisation was not carried out for the questionnaire elements, as various measures already have set cutoff scores, which, if standardised, would not retain their original interpretive value. Additionally, no thorough comparison between questionnaire elements is required.

A mediation analysis was used to assess how the VR-based CBM intervention affects alcohol-related behaviours. This analysis was designed to explore whether interventions that mainly target impulsive responses can indirectly influence more reflective processes related to alcohol use. Using the "lavaan" package in R, we examined both direct and indirect pathways of influence. To account for changes from pre- to post-intervention, we used difference scores for each variable. These difference scores serve to isolate the effects of the intervention by comparing the scores before and after the exposure. While we initially observed the direct effects of cognitive biases toward alcohol, as measured by the Implicit Association Test (IAT) and the Approach-Avoidance Task (AAT), on behaviours quantified by AUDIT scores, for the mediation analysis the primary focus was on investigating indirect effects. Specifically, we examined how metacognitive responses, measured through the PAMS and NAMS questionnaires, mediate the relationship between cognitive biases and subsequent drinking behaviours.

As a significance threshold 0.05 was used while trends towards significance were noted for p-values below 0.1.

Visualisation techniques included box plots to illustrate score distributions and radar graphs for the SCL-90. Most visualisations were generated using "R Studio". Mediation plots were edited in Adobe Photoshop, based on results obtained from "R Studio".

Results

Understanding the Sample

All data from participants 9 and 19 was omitted due to lack of post intervention data. Additionally IAT data for participants 1, 2, and 3 was not collected

The study included 18 university students, six females and 12 males, with an average age of 22.48 years. The participants' alcohol consumption levels, metacognitive beliefs, and psychological distress were assessed before and after the intervention using various questionnaires and tasks. Average times of the different tasks from the intervention can be found in Appendix B.

Table 1

General Intervention Measures

Measure	Mean	SD
	Pre-Intervention	
IAT D-Score	-0.03	0.34
AAT D-Score	0.32	0.63
AUDIT	12.20	5.09
NAMS	12.94	2.99
PAMS	28.89	3.97
SCL-90 Somatization	1.62	0.44
SCL-90 Anxiety	1.68	0.41
	Post-Intervention	
IAT D-Score	-0.17	0.26
AAT D-Score	0.07	0.42
AUDIT	11.41	3.99

NAMS	13.11	3.45
PAMS	27.94	4.01
SCL-90 Somatization	1.46	0.34
SCL-90 Anxiety	1.44	0.38

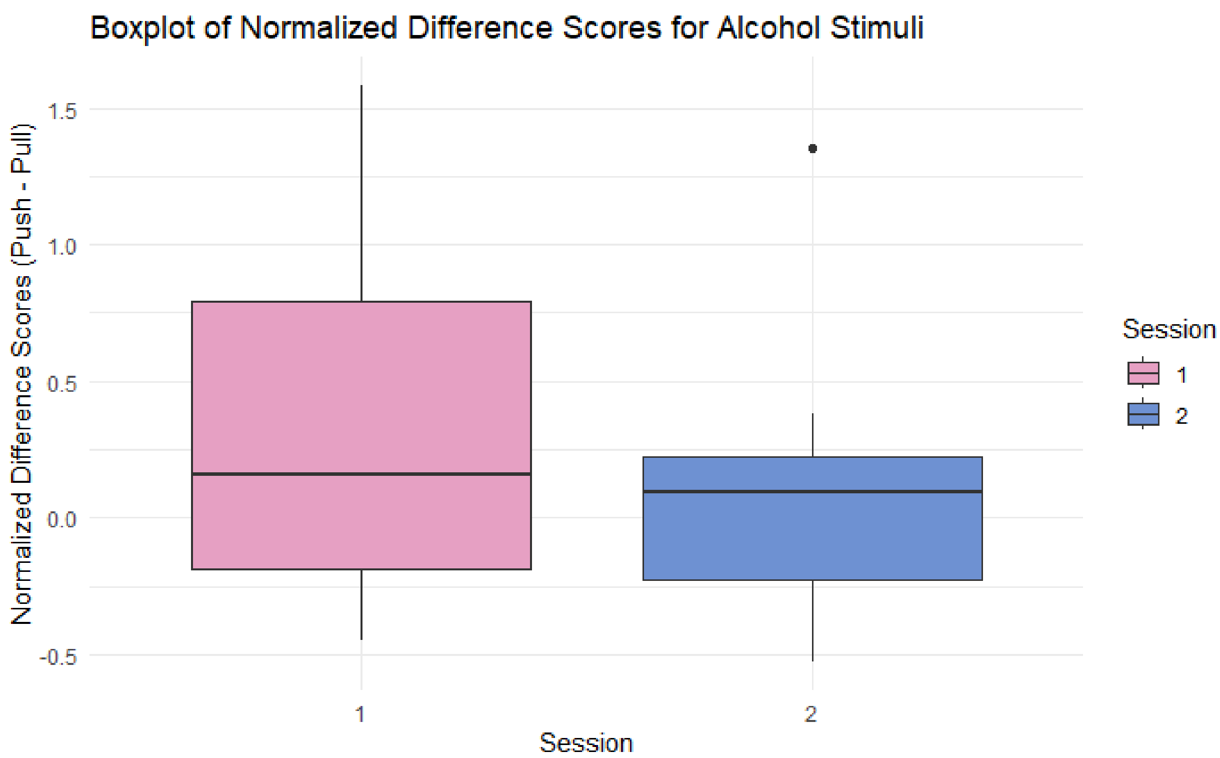
Note. IAT and AAT D-Scores reflect implicit attitudes and behaviors towards alcohol, with post-intervention results showing a shift towards less favorable biases. AUDIT scores, ranging from 0 (abstinence) to 40 (severe dependence), indicate a decrease in alcohol consumption. NAMS and PAMS assess metacognitive beliefs about alcohol, with changes suggesting a shift towards more negative views. SCL-90 scores, measuring psychological distress, show reductions in Somatization and Anxiety, indicating decreased distress post-intervention.

Efficacy of the VR-CBM Game

Post-intervention, there were notable decreases in the IAT D-Scores from -0.03 to -0.17 and AAT D-Scores from 0.32 to 0.07, alongside reductions in AUDIT scores from 12.20 to 11.41 (Table 1). These changes suggest improvements in implicit biases and reduced alcohol consumption. The paired t-test for D-Scores in the Approach-Avoidance Task (AAT) demonstrated a non-significant improvement post-intervention, revealing a mean difference of 0.25 ($t(17) = 1.34$, $p = 0.19$). This indicates a slight change in scores, but it was not statistically significant.

Figure 5

Box plot of AAT D-Scores by session

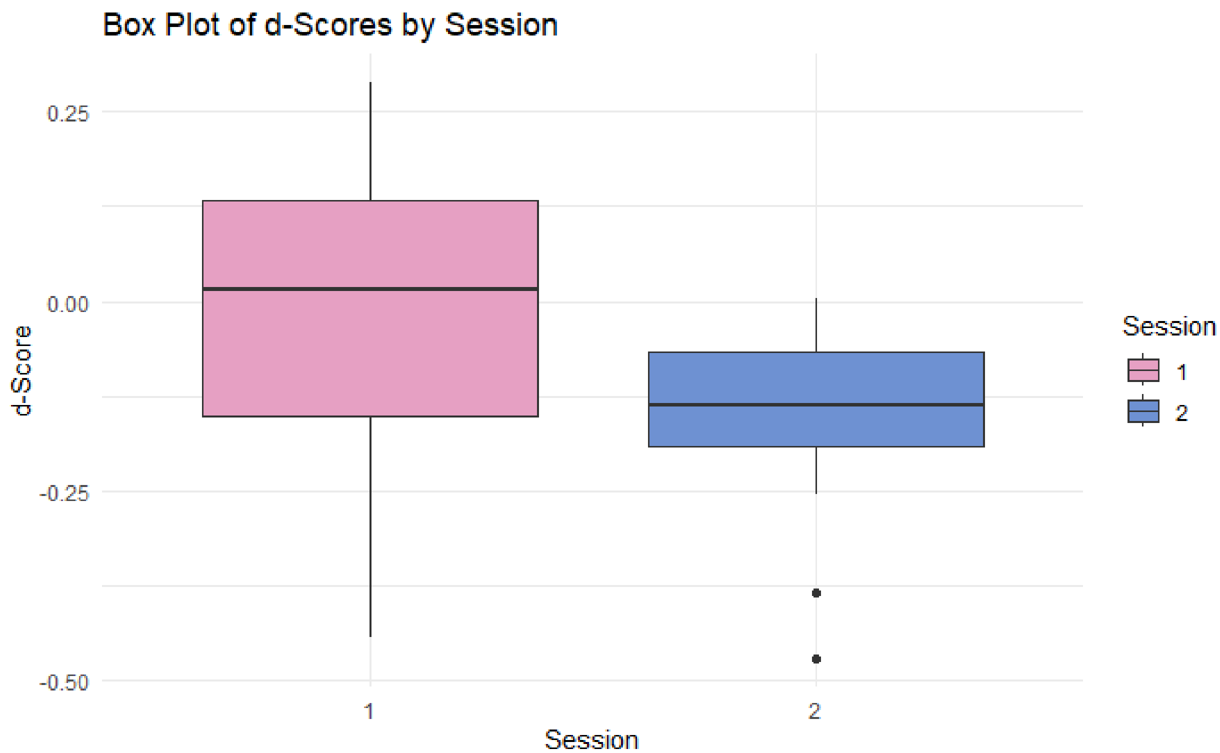


Note. This boxplot illustrates the D-Scores for alcohol stimuli in the Approach-Avoidance Task (AAT) across two sessions. The horizontal line within each box represents the median of the D-Scores, indicating the central tendency of participants' response times to alcohol-related cues. Session 1 is represented in pink, and Session 2 in blue. A decrease in the median value from Session 1 to Session 2 suggests an improvement in participants' tendency to avoid alcohol-related stimuli, indicative of a potential shift in approach-avoidance behaviour following the intervention. The plot also includes outliers, highlighting individual variations in response to the intervention.

The paired t-test for IAT D-Scores indicated a trend toward significance ($t(14) = 1.9$, $p = 0.07$), suggesting a favourable change post-intervention (Figure 6). Similarly, the AUDIT scores' trend toward significance ($t(17) = 1.9$, $p = 0.07$) supports a potential reduction in alcohol use (Figure 7).

Figure 6

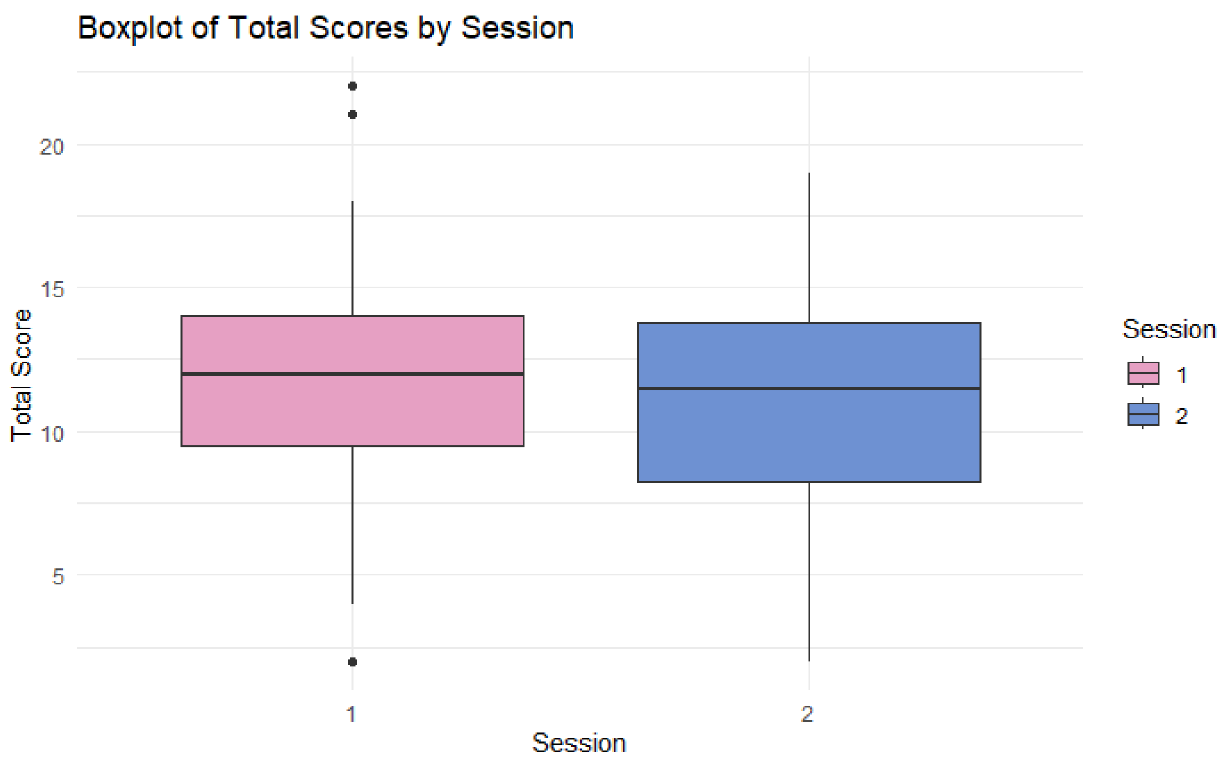
Box plot of IAT standardised D-Scores by session



Note. This boxplot represents the D-Scores from the Implicit Association Test (IAT) across two sessions. The median values, depicted by the horizontal line in each box, show the central tendency of participants' implicit associations between alcohol-related cues and either positive or negative connotations. Session 1 is represented in pink, and Session 2 in blue. A lower median D-Score in Session 2 suggests a shift towards less positive implicit associations with alcohol after the intervention. The presence of outliers in Session 2 indicates individual variations in response to the intervention.

Figure 7

Box plot of Audit scores by session



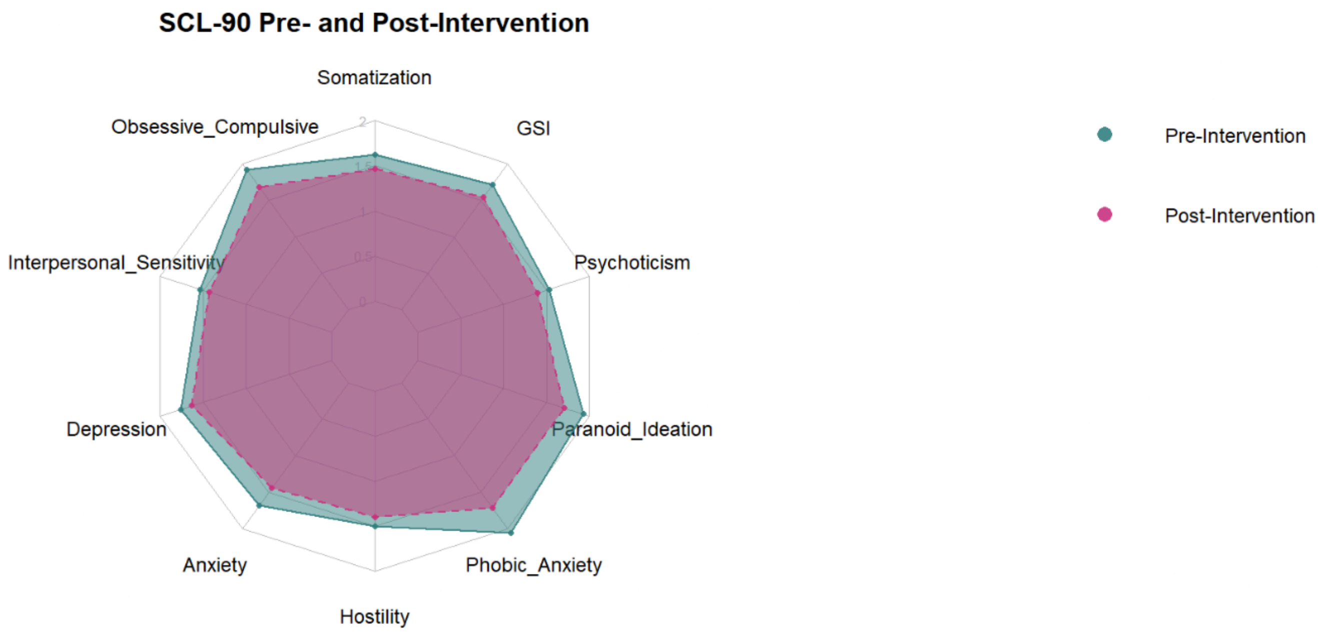
Note. This boxplot displays the distribution of total AUDIT scores before and after the intervention, representing participants' alcohol use patterns. The horizontal line within each box indicates the median score, which helps visualise the central tendency and the change in alcohol use from Session 1 (pink) to Session 2 (blue). Outliers are shown as individual points, indicating variations in responses among participants. The reduction in median values from the first to the second session suggests a potential decrease in alcohol consumption among the study participants.

SCL-90 Dimensions

Scores on the SCL-90 for Somatization and Anxiety, among others (See Appendix E for results of all SCL-90 dimensions), also showed decreases, from 1.62 to 1.46 and 1.68 to 1.44 (Table 1). Paired t-tests conducted on the SCL-90s different dimensions showed significant decreases in all dimensions except Interpersonal Sensitivity and Hostility (Appendix E), which as a whole is a favourable result. Significant ones being Somatization ($t(17) = 3.5$, $p = 0.002$) and Anxiety ($t(17) = 3.9$, $p = 0.001$) among others (Appendix E).

Figure 8

Radar plot of SCL-90 scores by session



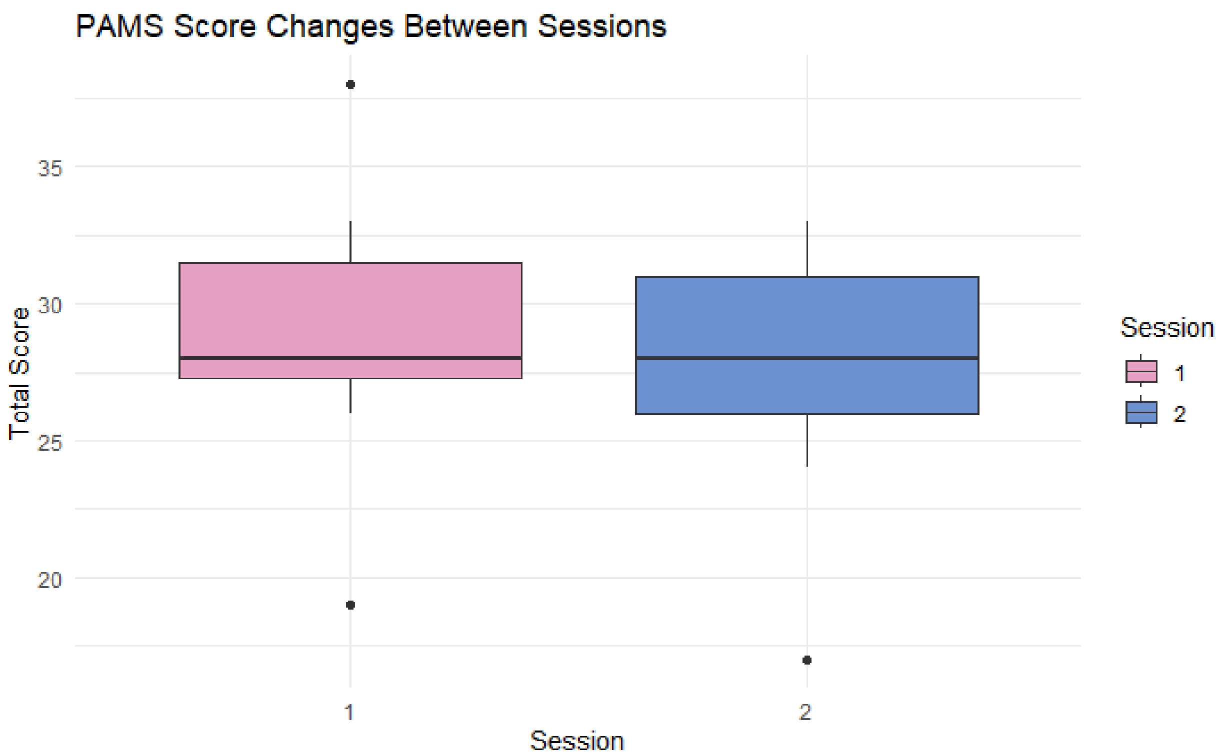
Note. This radar chart illustrates the changes in various psychological symptoms as measured by the SCL-90 from pre-intervention to post-intervention. Each axis represents a different symptom dimension with a maximum score of two, including Anxiety, Depression, Hostility, and others. The shaded areas indicate the symptom severity levels, with the innermost areas representing lower severity. The reduction in the post-intervention area (pink) compared to the pre-intervention area (purple) across multiple dimensions suggests an overall decrease in psychological distress among participants following the intervention.

Metacognitive Levels (PAMS/NAMS):

There was a slight increase in NAMS scores from 12.94 to 13.11 and a decrease in PAMS scores from 28.89 to 27.94, suggesting shifts in metacognitive beliefs about alcohol (Table 1). The PAMS paired t-test indicated a trend towards significance ($t(17) = 1.8$, $p = 0.07$), with a mean difference of 0.94 suggesting potential decrease in positive metacognitive beliefs about alcohol, which is a beneficial effect. The NAMS paired t-test showed no significant difference ($t(17) = 0.34$, $p = 0.73$), with a mean difference of -0.17, indicating a minimal decrease in negative alcohol metacognitions, thus showing a neutral effect.

Figure 9

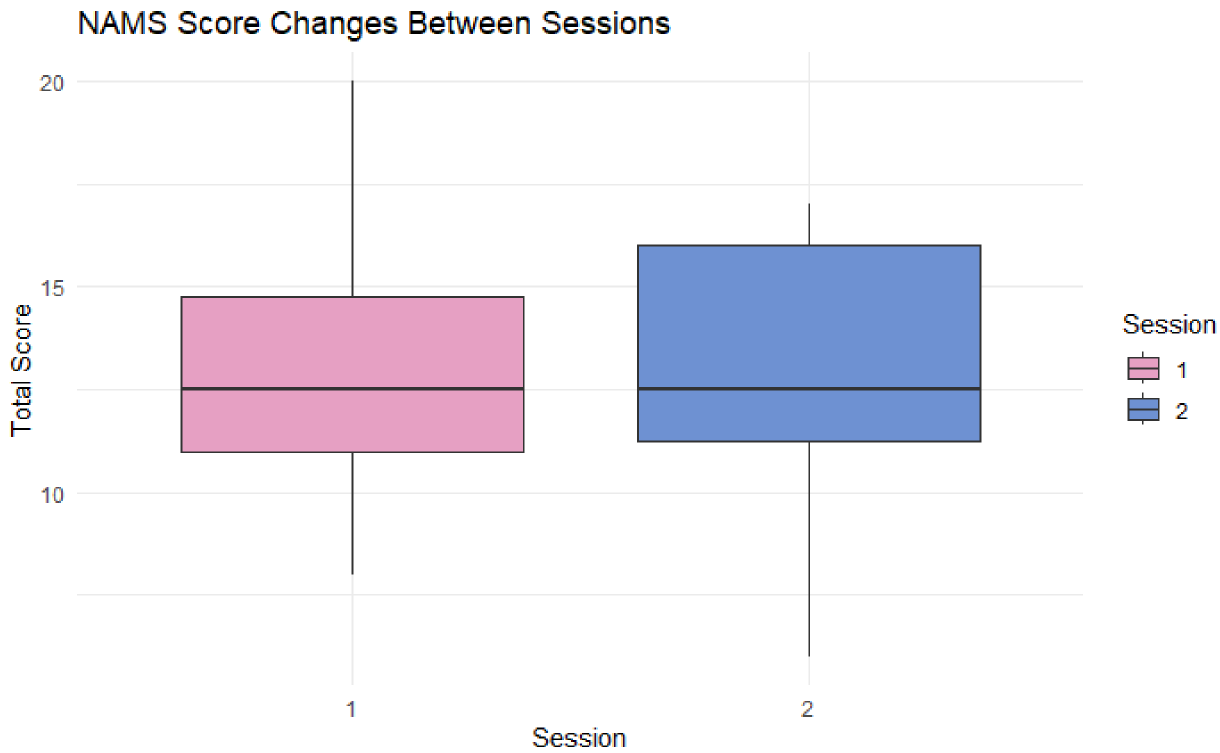
Box plot of PAMS mean score by session



Note. This box plot depicts the distribution of Positive Alcohol Metacognitions Scale (PAMS) scores across two sessions. Each box represents the interquartile range of scores, showing the median (central line) rather than the mean, and whiskers extending to the most extreme data points that are not considered outliers (depicted as individual points outside the whiskers). A decrease in median scores from Session 1 to Session 2 indicates a reduction in positive metacognitive beliefs about alcohol use, which is a desired outcome of the intervention.

Figure 10

Box plot of NAMS mean score by session



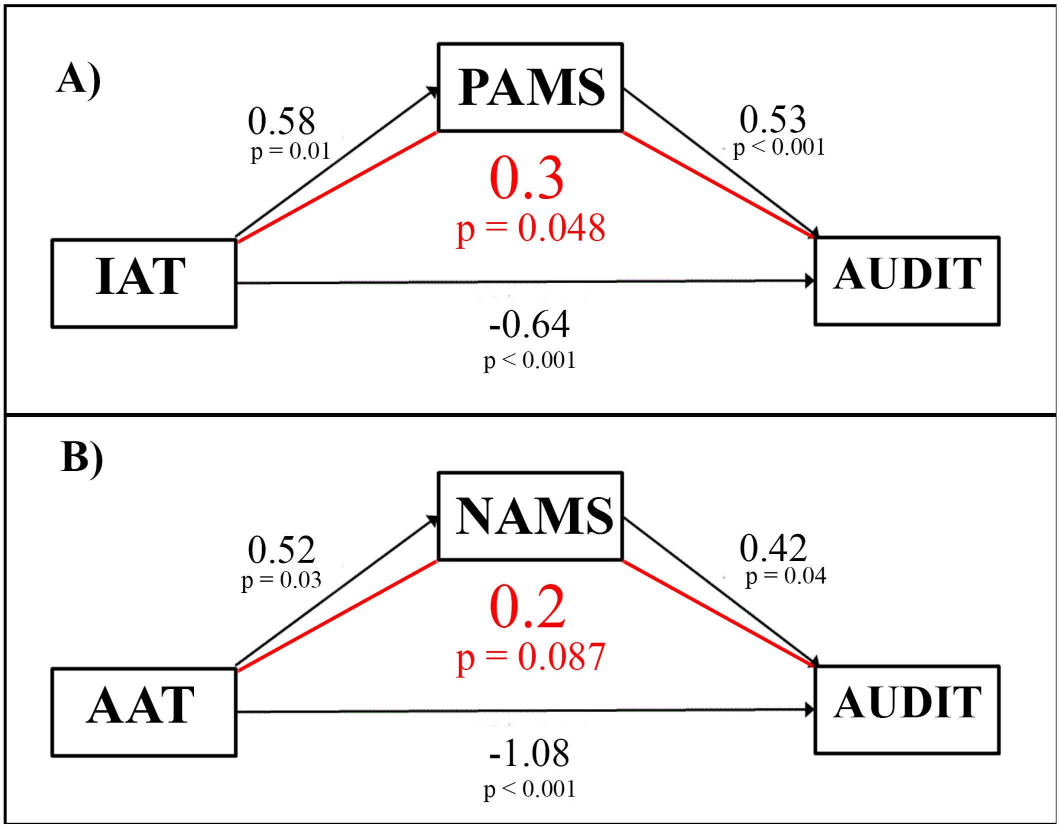
Note. This box plot displays the distribution of Negative Alcohol Metacognitions Scale (NAMS) scores before and after the intervention across two sessions. Each box shows the interquartile range, with the median indicated by the central line. Outliers are depicted as individual points beyond the whiskers. The plot visualises the minimal changes in NAMS scores, indicating a stable level of negative metacognitive beliefs about alcohol across the sessions. The median, rather than the mean, is used to depict the central tendency, providing a more robust measure against skewed data.

Mediation Analysis

Significant direct effects were observed for both IAT ($\beta = -0.59$, $p < 0.001$) and AAT ($\beta = -1.03$, $p < 0.001$) on AUDIT. The mediation model included both PAMS and NAMS as mediators. A significant indirect effect was found for the pathway from IAT through PAMS to AUDIT ($\beta = 0.29$, $p = 0.048$) (Figure 11). Additionally, a nearly significant indirect effect was found for the pathway from AAT through NAMS to AUDIT ($\beta = 0.087$, $p = 0.048$) (Figure 11). The model's overall fit was marginal, with a chi-square value of $\chi^2(1) = 3.1$ ($p = 0.08$) and an R-squared value of 0.75 for PAMS, indicating a substantial portion of the variance in AUDIT was accounted for through this mediated pathway. All results from the mediation analysis can be found in Appendix G.

Figure 11

Mediation Analysis plots



Note. This diagram displays two mediation models assessing the impact of cognitive biases on alcohol use behaviours, as measured by AUDIT scores, through metacognitive beliefs (PAMS and NAMS). Panel A shows the mediation of Positive Alcohol Metacognitions (PAMS) on the relationship between the Implicit Association Test (IAT) and AUDIT scores. Panel B shows how Negative Alcohol Metacognitions (NAMS) mediate the effect of the Approach-Avoidance Task (AAT) on AUDIT scores. Each path includes standardised regression coefficients and p-values, highlighting significant mediation effects in both models.

Discussion

Conclusion

This study focused on addressing the common issue of alcohol abuse among young adults by exploring underlying implicit biases related to alcohol use assessing the strength of automatic associations between alcohol-related stimuli and behavioural responses (Quigley & Marlatt, 1996; Ranker & Lipson, 2022). The added focus being on using a novel VR-based CBM protocol to modify approach-avoidance and attentional biases related to alcohol use among participants. This approach provided insights into the interaction between automatic (System One) and reflective cognitive (System Two) processes. The intervention was carried out over two sessions with 18 participants (Two participants decided to abandon the study after the first session). Several assessment tools were used: two cognitive tests (AAT and IAT) and various questionnaires (AUDIT, SCL-90, PAMS and NAMS).

With respect to the primary outcome of assessing the impact of a VR-based gamified intervention for modifying cognitive biases associated with alcohol use, a near significant reduction in IAT scores from pre to post suggests a trend towards the potential modification of implicit attitude toward alcohol. This trend, while not fully significant, indicates potential impacts of the VR-based CBM on participants' implicit biases towards alcohol, in line with Ghiţă and Gutiérrez-Maldonado (2018). The positive trend in IAT outcomes suggest that this novel approach was moderately successful.

The secondary objective of assessing the interaction between intuitive (System 1) and reflective cognitive (System 2) processes yielded a small favourable effect on positive alcohol metacognitive beliefs. While this result did not reach statistical significance, it aligns with the findings of Gierski et al. (2015), who noted that changes in metacognitive beliefs could signal shifts in cognitive processes relevant to addiction. The observed decrease in positive metacognitive beliefs about alcohol-related behaviour suggests potential enhancements in self-regulatory capabilities, which are crucial for reducing alcohol dependence, as supported by Stacy and Wiers (2010). However, the lack of significant changes in NAMS scores suggests that the intervention's impact on negative metacognitive beliefs might be limited, reflecting the complexity of modifying deeply entrenched negative biases, as discussed in the work of Cristea et al. (2016).

To assess the interaction between rapid, impulsive responses, as indicated by IAT and AAT scores, and their influence on alcohol consumption behaviours, which were measured through AUDIT scores a mediation analysis was performed. The interaction between automatic responses and behaviour was analysed in the context of how it is mediated by metacognitive processes, measured with PAMS and NAMS scores. Notably, the mediation analysis confirmed that PAMS scores, which reflect positive metacognitive beliefs about alcohol use, significantly modulated the relationship between the cognitive biases measured by the IAT and the outcomes on the AUDIT. This finding underscores the correlation between metacognitive beliefs and alcohol use patterns, in line with previous research, such as Gierski et al., (2015). The R-squared value for the indirect effects through PAMS and NAMS was significant, demonstrating meaningful mediation, thus confirming the critical role of metacognitive assessments in influencing alcohol consumption behaviours through changes in cognitive biases. The model's overall fit was found to be marginal, pointing to the need for cautious interpretation. The mediation effect involving AAT, NAMS and AUDIT scores was less pronounced, yet nearly significant, suggesting that not all metacognitive shifts have an equal impact on alcohol-related behaviours (Figure 11). Furthermore, research indicates that negative metacognitive beliefs about alcohol use can enhance the awareness of the harmful consequences of alcohol consumption and strengthen the motivation for change (Spada & Wells, 2008; Gierski et al., 2015). Overall, the mediation analysis, combined with existing literature, supports the inclusion of negative narrative elements. Although certain limitations should be taken into consideration when interpreting the mediation results, such as only having two time points, and a relatively small number of subjects.

The observed improvements in the somatisation and anxiety dimensions of the SCL-90, among others, suggest that VR-CBM interventions might influence not just specific cognitive biases but also broader aspects of affective states. Furthermore, the slight reductions across all SCL-90 dimensions imply that the intervention did not adversely affect participants' emotional or physical well-being. This outcome is particularly noteworthy given the potential for motion sickness with VR and the sensitive nature of addressing alcohol abuse, suggesting that the intervention was well-tolerated. These results are consistent with the observation that VR interventions reduce anxiety and other psychological distress symptoms by providing safe and controlled exposure to triggering stimuli, which can lead to desensitisation and improved coping mechanisms (Maples-Keller et al., 2017; Wiederhold & Wiederhold, 2005). The reduction in alcohol consumption from pre to post suggests that the intervention may contribute to lower alcohol use.

Additionally outliers were found in the data, but in order to present a fully transparent and holistic representation of the data, they were left in.

Discussion

Compared to traditional CBM, the integration of VR and gamification elements in this study aimed to enhance engagement and effectiveness (Ghiţă & Gutiérrez-Maldonado, 2018), addressing previous critiques about CBM's monotony as highlighted by Boendermaker et al. (2015).

While previous studies have shown clear benefits of CBM in reducing alcohol use, this study's results were more ambiguous, yet still showing a promising yet modest trend toward decreased alcohol consumption as per AUDIT scores. This modest improvement is noteworthy, especially considering the limited number of participants and the brief duration of the study. Moreover, the delivery of CBM in this study was done through VR, which might add further confounding variables to account for the aforementioned discrepancy. Additionally, the mediation analysis suggests that changes in System One processing may indirectly influence alcohol consumption measures, being mediated by metacognitions, providing a deeper understanding of how cognitive modifications might translate into behavioural outcomes.

This study shows that the dual-process theory can be effectively deployed to interpret and modify alcohol related behaviours which is consistent with the literature. It has been argued that modifying automatic (System One) responses can, to a certain degree, influence controlled (System Two) processes (Bechara et al., 2000). The mediation analysis confirms this and shows significant mediation pathways reflected in the PAMS scores. Consistent with the framework proposed by Stacy and Wiers (2010) the results underscore the importance of managing reflective processes in addiction treatment. The substantial predictive value of PAMS scores on AUDIT outcomes highlights the intricate relationship between automatic and controlled cognitive processes. This suggests that even subtle shifts in implicit biases can significantly impact broader psychological patterns and behaviours emphasising that interventions need to consider both System 1 and 2 (Stacy & Weirs, 2010).

The VR game designed for this study stands out as an innovative intervention tool aimed at shifting implicit attitudes towards alcohol through tailored tasks that reinforce learning and behavioural change. Furthermore, as the results suggest, it integrates both automatic (System One) and reflective (System Two) cognitive processes, providing a comprehensive framework for understanding and modifying behaviours related to alcohol use. Additionally, by simulating real-life situations, the game maintains relevance and engagement, which are critical for the success of behavioural interventions. The immersive nature of the VR environment enhances this engagement, potentially increasing the intervention's impact due to its captivating and interactive setup.

Limitations. Despite its innovative approach, the game design, as well as the intervention, encompass several limitations that require attention. One of the primary issues is the study's lack of a control group and small sample size. This limits the ability to attribute observed changes to the intervention and not to environmental or confounding variables and generalise the results given the low statistical power of the study. Furthermore, the effect sizes in the treatment groups of other studies on CBM for drinking behaviour are frequently reported to be more moderate. For instance, in their literature review, Cristea et al. (2016) discovered small to medium impact sizes for CBM treatments targeted at reducing alcohol intake. Similar to this, Wiers et al. (2015) found only slight declines in drinking behaviour, suggesting that the methodological constraints of this study may have inflated the results. Furthermore, the dosage of CBM in this study is lower compared to other studies, which may have limited the impact on behavioural change (Cristea et al., 2016). Additionally, the absence of qualitative data restricts insights into participants' subjective experiences and perceptions, which are crucial for a holistic understanding of the intervention's impact. The adjustment of standard CBM protocols to narrative coherence and gameplay engagement can be seen as another limitation, which was advised against by Boendermaker (2015). These modifications, which sometimes replace strict CBM tasks with Go/No-Go tasks or exposure priming, may affect the consistency and overall impact of the intervention (Boffo et al., 2019). The focus on short-term interactions within this environment also raises questions about the game's ability to influence long-term changes in alcohol-related behaviours or cognitive biases (Cristea et al., 2016). Moreover, existing literature has highlighted that employing university students as study participants poses inherent challenges, primarily due to their generally low intrinsic motivation to alter or diminish their alcohol consumption patterns. This demographic often lacks a personal incentive for change, complicating interventions aimed at modifying drinking behaviours (Boffo et al., 2019).

Recommendations for future research. To enhance the efficacy and applicability of VR-based interventions in addiction treatment, future research should focus on several key areas. Firstly, studies should consider including control groups to strengthen the validity of the findings by differentiating between effects due to the intervention and those from external factors. Secondly, incorporating more rigorous and standardised Cognitive Bias Modification (CBM) tasks within the narrative framework can ensure that therapeutic objectives are met without compromising the engagement offered by gamification. Alternatively CBM can be broadened to be able to include such a narrative-based approach. Expanding the participant pool to include a more diverse demographic can help improve the generalizability of the results. Additionally, integrating qualitative methods to gather participants' feedback can provide deeper insights into the subjective experiences and perceived effectiveness of the intervention. Finally, it would be beneficial to conduct longitudinal studies to evaluate the long-term impacts of VR-CBM interventions on behaviour change and relapse rates, thereby establishing more definitive evidence of their utility in real-world settings.

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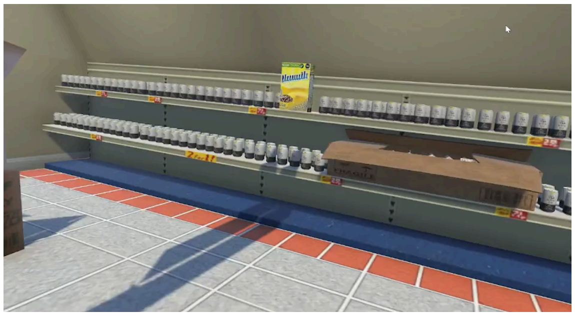
Appendix A

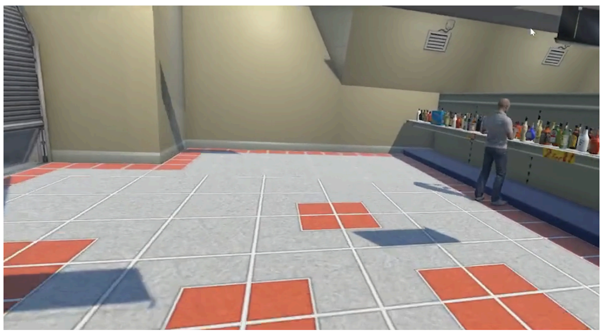
Gameplay

Link to game explanation: https://youtu.be/-10VVCXYKMM


00:49
Score: 2


DROP OFF





Appendix B

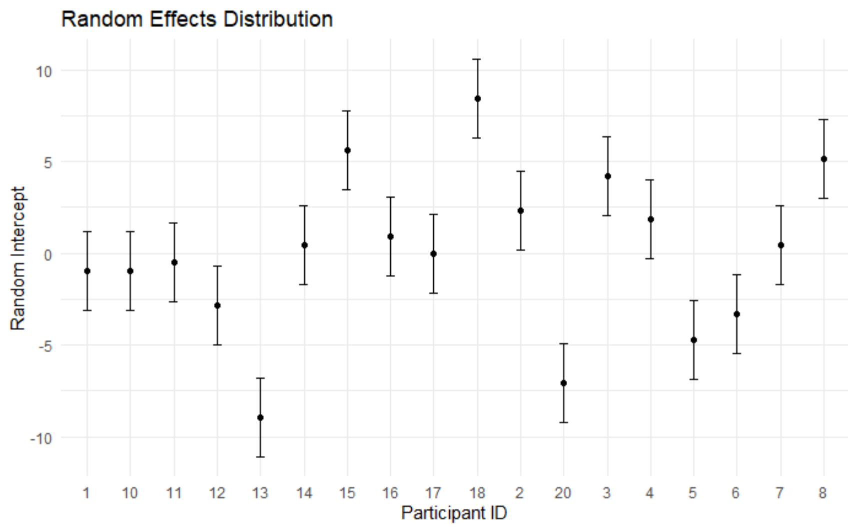
Durations for Activities over both sessions

Session	Activity	Average Duration (minutes)	SD
1	AAT	7.45	1.86
1	IAT	7.00	1.84
1	Game	27.36	5.73
1	Questionnaire	12.00	3.63
2	AAT	5.25	1.06
2	IAT	5.08	0.79
2	Game	14.31	3.43
2	Questionnaire	9.45	2.46

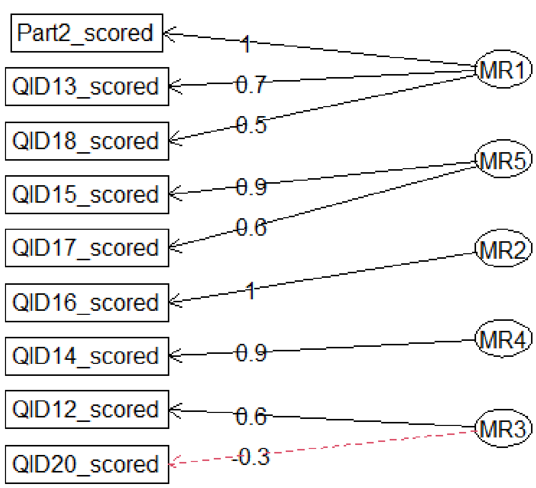
Appendix C

AUDIT further analysis

Statistical Measure	Value
Overall Cronbach's Alpha	0.77
Factor Analysis Factors Identified	5
Factor Analysis Total Variance Explained	74%
RMSEA (Root Mean Square Error of Approximation)	0.19
TLI (Tucker Lewis Index)	0.417
BIC (Bayesian Information Criterion)	-1.29
ANOVA p-value (Session)	0.5169
Linear Mixed Model AIC	194.3
Linear Mixed Model BIC	200.7



Scree Plot

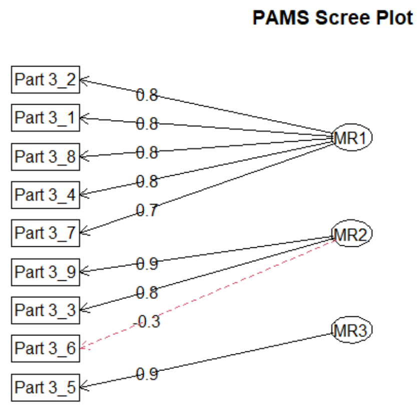


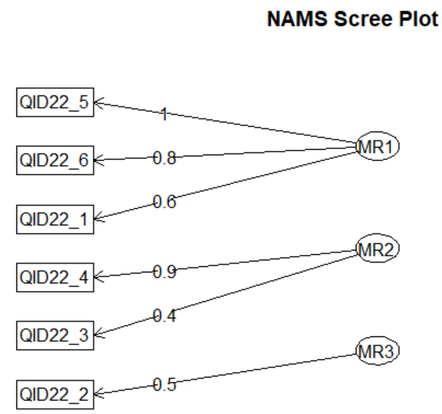
Appendix D

NAMS and PAMS further analysis

Metric	PAMS	NAMS
Cronbach's Alpha	0.7087	0.6649
Total Variance Explained (%)	63	64
Linear Mixed Model AIC	183.8	174
Linear Mixed Model BIC	190.1	180.4
Fixed Effects Session2 t Value	-1.938	0.357

Random Effects Variance (ID)	12.883	7.895
Residual Variance	2.137	1.95





Appendix E

SCL-90 all dimensions descriptives and T-Test

Dimension	Overall Mean	Mean SD	Change Score	t Value	df	p Value
Somatization	1.542	0.391	-0.157	3.527	17	0.0026
Obsessive Compulsive	1.803	0.427	-0.239	2.91	17	0.0098
Interpersonal Sensitivity	1.482	0.367	-0.111	1.909	17	0.0733
Depression	1.697	0.382	-0.128	2.755	17	0.0135
Anxiety	1.561	0.399	-0.232	3.884	17	0.0012
Hostility	1.449	0.354	-0.102	1.571	17	0.1345
Phobic Anxiety	1.894	0.56	-0.343	5.248	17	0.0001
Paranoid Ideation	1.82	0.43	-0.231	2.426	17	0.0267
Psychoticism	1.47	0.338	-0.135	2.9	17	0.01
GSI	1.632	0.348	-0.175	5.79	17	0.00002

Appendix F

Mediation Analysis R Code and output

Mediation Analysis

```
mediation_model <- '
  # mediators
  Change_PAMS ~ b1*Change_IAT + b2*Change_AAT
  Change_NAMS ~ c1*Change_IAT + c2*Change_AAT
  #outcome
  Change_AUDIT ~ a1*Change_PAMS + a2*Change_NAMS + d1*Change_IAT +
d2*Change_AAT
  #indirect effects
  indirect_effect_pams_iat := b1*a1
  indirect_effect_pams_aat := b2*a1
  indirect_effect_nams_iat := c1*a2
  indirect_effect_nams_aat := c2*a2
'
fit <- sem(mediation_model, data = wide_data)
summary(fit, fit.measures = TRUE, standardized = TRUE, rsquare = TRUE)
```

```
Regressions:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  Change_PAMS ~
    Chang_IAT (b1)    0.579    0.242    2.395    0.017    0.579    0.579
```

```
    Chang_AAT (b2)    0.291    0.245    1.187    0.235    0.291    0.287
  Change_NAMS ~
    Chang_IAT (c1)    0.178    0.250    0.713    0.476    0.178    0.178
    Chang_AAT (c2)    0.535    0.253    2.116    0.034    0.535    0.528
  Change_AUDIT ~
    Chng_PAMS (a1)    0.499    0.140    3.572    0.000    0.499    0.533
    Chng_NAMS (a2)    0.394    0.135    2.910    0.004    0.394    0.421
    Chang_IAT (d1)   -0.598    0.156   -3.842    0.000   -0.598   -0.640
    Chang_AAT (d2)   -1.028    0.156   -6.578    0.000   -1.028   -1.086

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .Change_PAMS       0.674    0.246    2.739    0.006    0.674    0.722
   .Change_NAMS       0.717    0.262    2.739    0.006    0.717    0.769
   .Change_AUDIT      0.197    0.072    2.739    0.006    0.197    0.241

R-Square:
                   Estimate
    Change_PAMS       0.278
    Change_NAMS       0.231
    Change_AUDIT      0.759

Defined Parameters:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
    indrct_ffct_pm    0.434    0.238    1.823    0.068    0.434    0.462
    indrct_ffct_nm    0.281    0.193    1.457    0.145    0.281    0.297
```