EXAMINING THE VIABILITY OF VIDEO GAME INTERVENTIONS FOR HEAVY ALCOHOL DRINKERS

A Dissertation

by

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Submitted to the Graduate and Professional School of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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December 2022

Major Subject: Psychology

ABSTRACT

Alcohol cue reactivity is a process in which cues typically signaling alcohol administration come to elicit conditioned responses such as strong, positive emotions and cravings for alcohol in heavy drinkers. Research evidence suggests that impaired memory and/or attentional processes may, in part, contribute to cue reactivity for alcohol. Virtual video games can offer an improved way to measure cue reactivity and/or deliver cue exposure interventions for alcohol, although evidence for their potential efficacy remains understudied. In a series of studies, we examined the ability of novel video games to 1) measure attention and working memory, 2) measure cue reactivity in terms of in-game scoring and 3) examine subjective emotions and cravings for alcohol post-gameplay. We found that our games were significantly correlated with established measures of attention and memory. Performance on one of the games was also dependent upon participants' drinking levels. Further, a heavy drinking sample playing game versions embedded with alcohol stimuli reported 1) increased cue reactivity for alcohol imagery after a single gaming session, and 2) decreased cue reactivity for neutral imagery after repeated gaming sessions. Our results suggest that video game interventions for heavy alcohol drinkers can decrease their positive feelings and cravings for alcohol, although this is likely influenced by the type of game played and length of exposure received.

DEDICATION

I dedicate this dissertation to my parents, who nurtured and supported me throughout my personal and professional life.

ACKNOWLEDGEMENTS

First, I would like to acknowledge my advisor Dr. Sherecce Fields. Dr. Fields took a chance on me and admitted me into her lab for graduate study. As a result, I benefitted from her leadership and investment. Second, I would like to acknowledge Dr. Hart Blanton. Dr. Blanton invested time and energy into mentoring me, for which I am very grateful. Third, I am so indebted to Dr. Chris Burrows for lending his programming expertise in developing the video games in this project. I could not have finished this without his help. I also want to acknowledge Dr. Leslie Morey and Dr. Mary Meagher for their professional guidance throughout graduate school, which helped turn this initial idea into a better, more practical research project.

I must acknowledge my friends and family as well because they provide me with unconditional love and support. Mom, you helped me feel heard and understood during graduate school. Dad, your encouragement and support gave me strength to actualize my potential. Auntie Sheila, you always reminded me to take care of myself. My colleagues and friends too, namely Tristin, Kendall, Nam, Alex, Tabina, Jane, Wan, Mike P., Mike S., Sara, Bethany, Jordan, Lani, Justin, Sam, Jaime, and others. You all have helped me achieve personal and professional growth. Lastly, I would like to thank Deicy, a post-baccalaureate member of our research lab, who aided in data collection and cleaning for this study.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Professor Sherecce Fields and Professors Leslie Morey and Mary Meagher of the Department of Psychological & Brain Sciences and Professor Hart Blanton of the Department of Communication.

The video games in this study were created in the Unity 3D game engine by Post-Doctoral Research Associate Chris Burrows of the Department of Communication at Texas A&M University. All other work conducted for the dissertation was completed by the student independently.

Funding Sources

Graduate study was supported by a fellowship from Texas A&M University.

NOMENCLATURE

ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
AUD	Alcohol Use Disorder
CPT	Conners' Continuous Performance Test
OSPAN	Operations Span Task
HRT	Hit Reaction Time
HRT SD	Hit Reaction Time Standard Deviation
HRT BC	Hit Reaction Time Block Change
HRT ISI	Hit Reaction Time Interstimulus Interval
SPSS	Statistical Package for the Social Sciences

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION

Problem of Heavy Drinking

Alcohol use is a chronic and pervasive public health problem. Adulthood, especially young adulthood, is a time of transition and growth and excessive alcohol use during this life period can impede the successful mastery of important life tasks, like pursuing college, working full-time, and forming serious relationships. Alarmingly, Substance Abuse and Mental Health Services Administration (SAMHSA) national survey data reports nearly 1 in 10 U.S. adults reported binge alcohol consumption (at least 4 drinks for women/5 drinks for men, in a row) on 5 or more days within the past month (Welty et al., 2019).

Termed ***heavy drinking***, this dangerous pattern of alcohol use tends to peak around the early twenties (Patrick et al., 2019). Consistent heavy drinking drastically increases risk for an Alcohol Use Disorder (AUD) and associated health risks, including interpersonal violence, accidental injuries, and premature mortality (World Health Organization, 2018). The total social cost of excessive drinking is estimated at $249 billion, including losses to workplace productivity (72%), healthcare (11%), criminal justice (10%), and motor vehicle collisions (5%; Sacks et al., 2015). These data show that heavy drinking is a highly prevalent and costly public health concern, on par with smoking and obesity.

Alcohol Cue Reactivity and Heavy Drinking

While the initiation of alcohol drinking is voluntary, the maintenance of heavy drinking patterns is often the result of certain automatic learning processes. Over time, the cognitive, behavioral, and physiological systems controlling aspects of alcohol seeking and consumption can become automatized, resulting in behavior that is compulsive and stimulus-bound (Tiffany, 1990).

One example of such an automatized process is called ***cue reactivity***. Cue reactivity is a Pavlovian conditioning process by which initially neutral drug-related stimuli (*Unconditioned Stimuli*) become reliably associated with drug consumption (*Unconditioned Response*), transforming into cues (*Conditioned Stimuli*) that trigger automatic reactions (*Conditioned Responses*). For example, repeated pairing of a particular pint glass (*Unconditioned Stimulus*) with alcohol drinking (*Unconditioned Response*) over time can eventually cause the pint glass (now a *Conditioned Stimulus*) to elicit alcohol-related thoughts, alcohol craving, and motivations to drink alcohol (now *Conditioned Responses* to the pint glass).

As outlined in Drummond's (2000) model of cue reactivity, these automatic reactions to alcohol stimuli can manifest in a variety of forms, such as behavioral biases, physiological responses, and expressive motivation for drugs in the presence of drug cues. For alcohol drinkers, this results in alcohol-related contexts or objects (e.g., beer bottles, bar environments) taking on *incentive salience.* Incentive salience assigns hypersensitivity to the motivational effects of drugs and drug cues, resulting in a general reactivity towards cues predicting drug use (Berridge & Robinson, 2016). For alcohol drinkers, this reactivity gets stronger with repeated pairings of cues and alcohol use, resulting in alcohol cues being most salient for heavy drinkers. This salience triggers craving and approach behaviors for alcohol, raising the probability of repeated alcohol consumption the more these stimuli are paired together.

Mechanisms of Alcohol Cue Reactivity

One important component not considered in Drummond's (2000) model of alcohol cue reactivity are cognitive manifestations of incentive salience. The hypersensitivity assigned to drug stimuli reflect the rewarding value of those cues, making them attractive and attention-grabbing. This requires cognitive resources, perhaps uniquely attention and working memory resources.

While the cue reactivity paradigm has been shown to elicit widespread brain activity across regions theorized to involve attention and working memory, little work has been undertaken to systematically examine the unique role(s) these cognitive processes play within *incentive salience* for alcohol itself (Hill-Bowen et al, 2021).

Attention

Attention has been defined as the selective processing by which information is selected and processed with priority (Chun et al., 2011). For alcohol, more experienced drinkers display biases in their attention towards alcohol stimuli compared to neutral stimuli, like quick reaction times to and selective eye movements towards alcohol-related reward cues, like pictures of beer, wine, and liquor (Manchery et al., 2017; Roy-Charland et al., 2017). Poor attention, therefore, may relate to over-processing of alcohol-related stimuli as compared to other stimuli in the visual field. Relatedly, the self-regulation of attention, or being better able to selectively control one's cognitive processing, has been theorized to be a major component of treatment response during AUD recovery (Wilcox et al., 2014). Therefore, increasing one's purposeful attentional processing may have beneficial effects.

Working Memory

Working memory has been defined as the process by which information is held in mind temporarily and manipulated (Diamond, 2013). Drinkers tend to display deficits in their working memory ability (Carbia et al., 2017) and, vice versa, presentations of alcohol-related reward cues produce interference on cognitive tasks requiring working memory (Cox et al., 2006; Nguyen-Louie et al., 2016). Heavy drinking may, therefore, interfere with working memory, such that there is perhaps an over-processing of alcohol-related stimuli as opposed to other stimuli. Similarly, better working memory performance appears to be a cognitive indicator of the ability to reduce alcohol drinking among those seeking treatment (Bates et al., 2013). Training one's working memory, therefore, could serve as an approach to intervention.

Cognitive Biases and Craving

As alcohol cue-and-response pairings increase with continued heavy drinking, these cues reliably and automatically interfere with heavy drinkers' cognitive control. The incentive salience associated with these cues may deplete cognitive control, a limited resource, and manifest as overt attentiveness and short-term memory for alcohol stimuli. As attention and working memory are interdependent cognitive systems influencing one another (Engle, 2018; Oberauer, 2019), one or both of these mechanisms may underlie the biased hypersensitivity of heavy drinkers' awareness for alcohol cues. In sum, the underlying reason for alcohol's incentive salience may at least partially be explained by cognitive control being depleted for stimuli predicting alcohol use, stimuli that have been repeatedly conditioned to do so through Pavlovian learning.

Theory suggests incentive salience leads to a narrowing of cognitive scope, to assist in pursuing reward (Harmon-Jones et al., 2013). Following this logic in terms of alcohol, alcohol cues likely narrow the cognitive scope of heavy drinkers to focus on the conditioned stimuli that are likeliest to predict the receipt of alcohol (e.g., glasses, bottles, bar environments, pictures/advertisements of alcohol, etc.). The resultant biases conditioned through this automatic process have been strongly tied to alcohol craving and associated motivational states. The effect for cue reactivity on self-reported alcohol craving has been characterized as medium in size (Carter & Tiffany, 1999). For example, alcohol cue exposure has been shown to simultaneously induce greater subjective craving and associated attentional biases towards alcohol stimuli when compared to control stimuli (Ramirez et al., 2015). Field and colleagues (2015) even found that those high in alcohol craving, who only drank beer occasionally, displayed more biases in their attention, preference, and approach motivations for alcohol versus control pictures, compared to a low craving group. Thus, cognitive biases and cravings for alcohol are inter-correlated phenomenon that have been reliably induced by the cue reactivity paradigm, even in non-dependent drinkers.

Cognitive Bias Modification Tasks

Fortunately, alcohol-related cravings and approach motivations can be modified and potentially reduced through the deployment of tasks designed specifically to modify these alcohol-related cognitive biases. Cognitive tasks for heavy drinking may combat alcohol cue reactivity by strengthening one's deliberate use of attentional and working memory resources, potentially increasing the ability of subjects to simultaneously decrease their cravings and motivations to drink over time. Such tasks may promote new *inhibitory learning* for alcohol stimuli, such that conditioned alcohol stimuli (e.g., a pint glass repeatedly paired with alcohol) is purposefully and continually presented without alcohol. Over time, the power of this conditioned stimulus to elicit its conditioned response becomes inhibited: since it no longer reliably predicts alcohol receipt, the stimuli's incentive salience becomes neutralized.

For example, approach-avoidance tasks for alcohol involve using a joystick to push away alcohol cues and pull non-alcohol stimuli towards oneself. Continued persistence at this task is designed to correct heavy drinkers' automatized approach behavior, one form of cue reactivity (Drummond, 2000). Tasks including such methodology can reduce cue reactivity in brain regions associated with alcohol arousal and craving (Wiers et al., 2015). Tasks which modify the narrowing of attentional scope for alcohol cues can work in tandem. These tasks use a 'broadening' manipulation of attention which can reduce the automatized motivation for attentional processing for alcohol stimuli in heavy drinking samples (Ryerson et al., 2017). Other retraining tasks designed to orient attention away from alcohol cues towards more neutral ones can decrease heavy drinkers' attentional biases (Schoenmakers et al., 2010) and have even been documented to reduce post-training alcohol consumption at a 3-month follow-up (Fadardi & Cox, 2009).

Similarly, working memory tasks have been documented to reduce alcohol intake at 1-month follow-up by purposefully interfering with short-term memory storage, reducing heavy drinkers' automatic preferences for alcohol-related stimuli (Houben et al., 2011). The success of these tasks may rely on strengthening different aspects of cognitive control to counteract the automaticity towards alcohol cues delivered by incentive salience over time through Pavlovian learning. In conjunction with existing intervention, such cognitive bias modification tasks may reduce or stabilize drinking outcomes for higher-risk individuals compared to treatment-as-usual.

Improvement via Gamification

While cognitive bias modification tasks show some promise as a tool to reduce the incentive salience of alcohol-related stimuli, there are several characteristics of these tasks that limit their effectiveness as a tool for intervention. They are often long, laborious, and frustrating for participants. For example, some task protocols require multiple days of increasingly difficult training sessions for several weeks. Due to their demanding nature, disengagement from task protocol commonly occurs and motivational techniques to ensure compliance are needed (Bickel et al., 2014). Another major challenge of such tasks is the poor findings regarding their transfer-of-effects: cognitive training tasks for heavy drinkers do not necessarily lead to reductions in drinking outcomes or associated cognitive biases outside of the training context (Lumsden et al., 2016; Ramirez et al., 2015). This limits the ability of these tasks to properly alleviate or de-escalate heavy drinking and AUD, a debilitating real-world problem likely associated with several layers of addiction-related learning dysfunction.

A solution to these and other practical issues may lie in 'serious' games. While definitions for serious games vary, given their application within a broad spectrum of areas, most researchers agree on a core meaning: "serious games are (digital) games used for purposes other than mere entertainment (Susi et al., 2007)." Historically, serious games tend to have strong themes that "provide users with specific skills development or reinforcement learning" where "skill development is an integral part of product (Entertainment Software Rating Board, 2007)." For example, in the field of healthcare, serious games tend to focus around providing patients with knowledge and habits to improve their health, reduce risks associated with negative health outcomes, or enable coping with health problems (Ratan & Ritterfield, 2009).

Using a serious game approach may improve typical cognitive bias modification tasks for AUD. Incorporating elements of video game playing, such as point scoring, competition, or rules of play, often increases players' motivation and long-term engagement for effortful cognitive tasks. This may increase the usability of these tasks and boost their ecological validity in the real-world (Lumsden et al., 2016). For example, adding in gaming elements to cognitive tasks for heavy drinkers has been shown to increase their motivation for effortful participation (Boendermaker et al., 2015). One gamification study of alcohol cue exposure therapy even reduced cue-elicited cravings after only eight gaming sessions (Lee et al., 2007). 3D animation techniques and the sense of virtual reality characteristic of video games provides a more diverse range of situations and stimuli than traditional cognitive tasks, potentially resulting in an increased generalization of treatment effects through layered types of associative learning. Approaches delivered in virtual formats may also have the potential to alleviate behavioral health disparities by extending the therapeutic reach of such programs to underserved and at-risk populations (Fleming et al., 2017).

‘Gamifying’ cue reactivity paradigms, therefore, is one exciting and concrete strategy to overcome some of the limitations of typical alcohol-related cognitive training tasks. A nationally representative survey indicated 67% of American adults play videogames for entertainment, with 77% of players gaming either online or in-person at least once per week (Entertainment Software Association, 2020). This means that the use of entertainment videogames as a tool for delivering alcohol interventions has tremendous potential to influence young adults’ heavy drinking patterns and overall alcohol consumption through measurement and reductions in their reactive biases.

The Present Study

Alcohol cue reactivity can potentially be measured, and subsequently reduced, using a serious video game approach, which would lead to better outcomes for heavy drinkers at risk for AUD. However, to develop and test a serious game prevention tactic for heavy drinking, we must understand the dynamics of alcohol-related biases and cue reactivity towards alcohol stimuli in virtual gaming settings. The current project addresses this need and tests the viability of a cue reactivity paradigm within novel virtual gaming settings. Cue exposure treatments are hypothesized to work through inhibitory learning, i.e. the incentive salience of drug cues becomes inhibited through repeated exposure to cues without paired drug administration, resulting in such cues undergoing Pavlovian extinction over time. If signs of incentive salience were to first exist in the context of a video game, this would provide evidence for virtually delivered cue exposure treatments. This framework could potentially serve as an efficacious and economic model of service delivery within larger AUD prevention programs.

Although a relatively young field, most existing serious game interventions for heavy drinking tend to target individuals with severe and long-standing AUD. However, it is equally important to examine the potential of serious games as a prevention tactic for at-risk populations, i.e. heavy drinkers at risk for progression into severe AUD. First, examining the viability of video game measurement of alcohol cue reactivity is necessary.

To explore the viability of video game-based measurement of alcohol cue reactivity, the objectives of this dissertation are as follows:

<u>Objective 1</u>: **Explore cognitive mechanisms related to video game play.** Our games are theorized to measure cognitive bias using different underlying mechanisms. Our *Spaceship Blaster* game targets attention: players must focus their attention on navigating through an asteroid field while distracting objects (i.e., alcohol versus water cues) flash on-screen. Our *Word Blaster* game targets working memory: players must remember and type in words while traveling through different environmental contexts (i.e., bar versus neutral environments). Our *Dance Off!* game also targets working memory: players must remember letter sequences and type them out to make their avatar dance while distracting objects (i.e., alcohol versus water cues) flash on-screen. Hence we were interested in determining whether our games were associated with the underlying mechanisms that we proposed. To examine these associations, participants will play all three games and between-game performance on tasks of attention and working memory will be examined.

<u>Hypothesis 1</u>: Scores for *Spaceship Blaster* will positively correlate with scores for a behavioral measure of attention, while scores for *Word Blaster* and *Dance Off!* will positively correlate with scores for a behavioral measure of working memory.

Objective 2: **Validate the use of serious games to detect differences in alcohol cue reactivity.** Our study incorporates a 2 (Heavy Drinker vs. Abstainer) X 2 (alcohol vs. neutral embedded cues) factorial design. Our study involves these two groups of participants playing versions of serious video games designed to elicit alcohol cue reactivity. To succeed in these games, players must ignore distractor alcohol stimuli and focus their cognitive resources on game performance.

Hypothesis 2: The presence of alcohol distractor cues will result in the lowest scores on in-game game performance for heavy drinkers, relative to abstainers and relative to game play with neutral distractors.

Objective 3: **Test if serious game cue reactivity elicits craving and associated motivational states.** Before and after video game play, we will assess measures of individual alcohol craving and cue reactivity.

Hypothesis 3: The presence of alcohol distractor cues will temporarily result in higher scores for self-reported craving and associated motivational states in heavy drinkers, relative to abstainers and relative to game play with neutral distractors. This effect will be examined over repeated gaming sessions.

CHAPTER II

METHOD

Descriptions of Video Games

To meet the objectives of our study, we developed three unique video games. We hypothesized that players would be required to use aspects of attention, working memory, or both constructs in order to succeed in playing these games and score more points. Further, two unique versions of each game were created that either contained alcohol stimuli (our Experimental condition) or neutral stimuli (our Control condition). Descriptions of each and screenshots of gameplay are provided below:

Spaceship Blaster

In this game, players pilot their personal spaceship through an outer asteroid field, where they can “blast” asteroids using their ships lasers. Players’ main objective is to drive their spaceship through as many rings in space as possible within the time limit. Each ring passed through earns players one point. However, players must pay close attention when piloting their ships, as crashing into too many obstacles will force a reset. If this occurs, players will lose their accumulated points. Points are earned in relation to total amount of rings driven through (Total Score) and total amount of asteroids crashed into (depleted Armor Score).

Our experimental manipulation is revealed when either alcohol cues, in the form of pictures of beer, wine, or liquor, or neutral cues, in the form of pictures of water, appear for brief, 3-second flashes in the corner of players’ computer screens. These cues virtually swivel and move to become attention-grabbing, distracting players from their objective. Players who are better able orient their attention away from these cue distractors and refocus their attention on navigating through the game’s rings will hypothetically earn more points, as the game requires players’ attention and concentration to earn a high score.

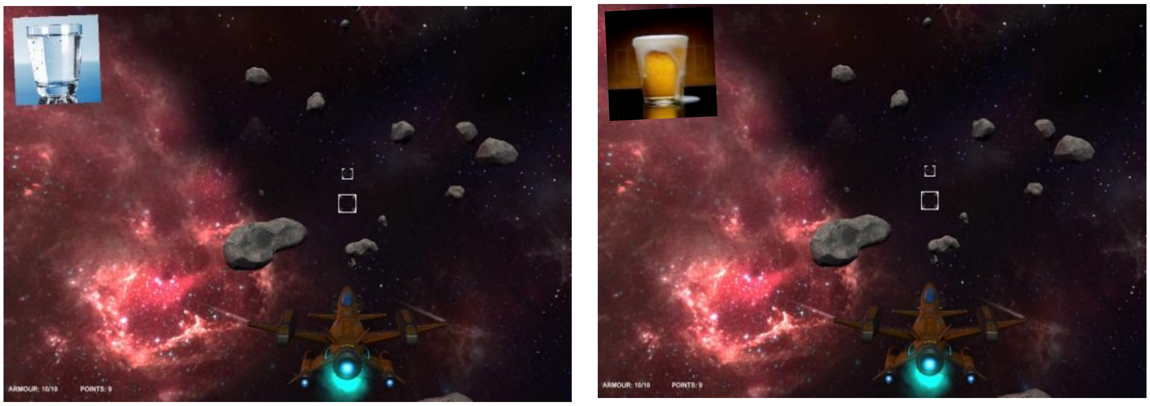

Figure 1 *Spaceship Blaster* game screenshots
With neutral water (Control condition; left) and distractor alcohol (Experimental condition; right) embedded cues.

Word Blaster

In this game, players quickly type in words as they appear on the screen in order to destroy, or “blast,” virtual objects. Players’ main objective is to remember different words as they are presented on screen, keep them in short-term memory, and quickly type out the words to blast as many objects as possible within the game's time limit. Points are earned for successfully destroyed objects, with extended combos earning extra points. Correctly typing multiple words in a row increases players’ level and sends harder words their way.

Our experimental manipulation occurs when players encounter background environments that are either neutral, consisting of a plain warehouses and red floating orbs, or alcohol bar environments, complete with barstools, liquor and wine shelves, beer taps, and floating beer bottles. Players who are better able to utilize their working memory by remembering words and typing them out in the presence of distractor stimuli will hypothetically earn more points, as the game tasks players’ working memory capacities to earn a high score.

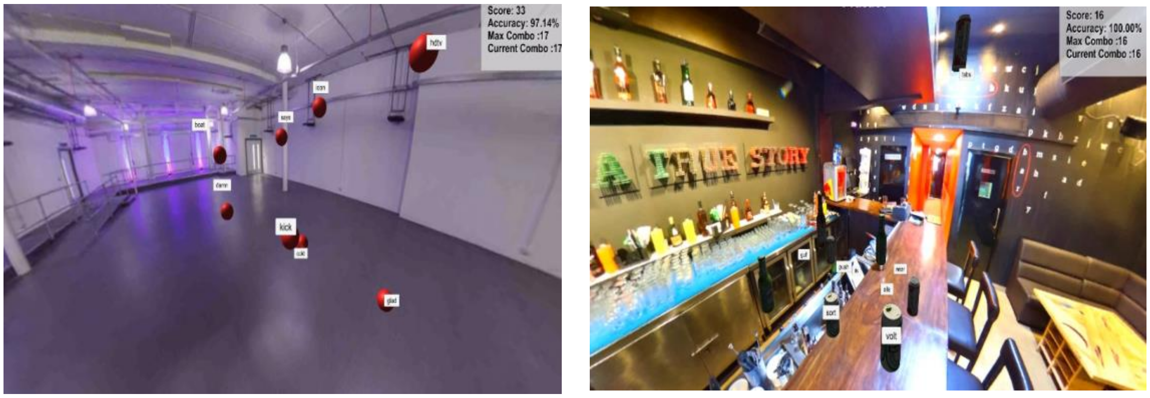

Figure 2 *Word Blaster* game screenshots
With neutral (Control condition; left) and distractor alcohol (Experimental condition; right) embedded cues.

Dance Off!

In this game, players remember and copy sequences of dance moves made by their on-screen rival. Their objective is to remember a particular letter sequence as it is presented, hold the sequence in short-term memory, and then type it out in the correct order to outperform their dancing rival. Points are earned for each correct letter sequence entered at the appropriate time. Points are deducted from players' scores for incorrect letters, typing at the wrong time, or entering letters in the incorrect order. Extended combos of correct letter sequences earn more points and require players to remember longer sequences.

Our experimental manipulation is revealed when either alcohol cues (i.e., pictures of beer, wine, or liquor) or neutral cues (i.e., pictures of water) appear for brief, 3 second flashes in the corner of players' computer screens. These cues virtually swivel and move and are designed to interfere with players' short-term memory storage. Players who are better able to utilize working memory by remembering sequences and type them out in the presence of distractor stimuli will hypothetically earn more points, as the game tasks players' working memory capacities.

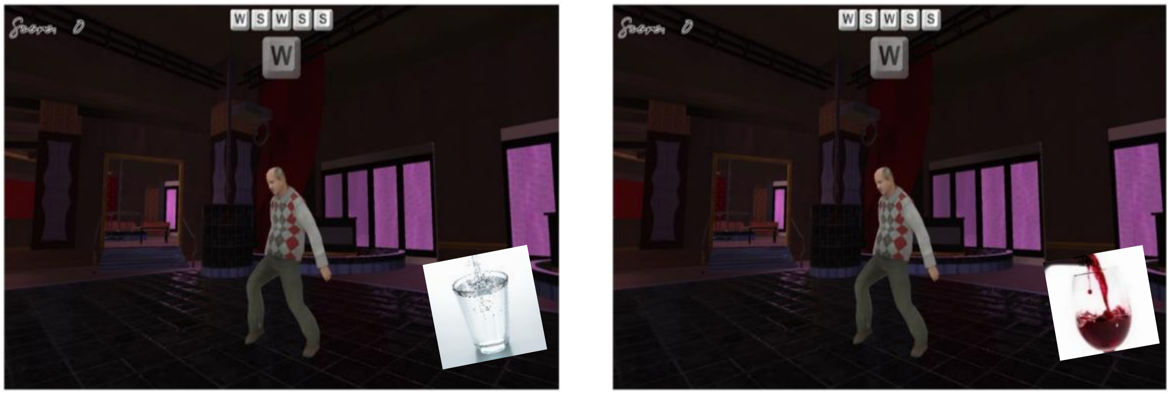

Figure 3 *Dance Off!* game screenshots
With neutral (Control condition; left) and distractor alcohol (Experimental condition; right) embedded cues.

Study One

Participants

To meet Objective 1 and test Hypothesis 1, subjects were recruited from the Psychology SONA pool at Texas A&M University. Participants consisted of undergraduates (*N* = 101) who received course credit in exchange for their participation. The average age was 19.2 years old (SD_{age} = 1.9 years). The gender breakdown was 58% female, 41% male, and 1% identified as non-binary. Participants mostly identified as White (65%), with lesser representation of Hispanic (23%), Asian (7%), and Other (1%) ethnicities.

Procedure

Participants were invited to the laboratory and provided their informed consent. They completed the study entirely at a desktop computer. First, a short questionnaire asked about their demographics. Next, they were assigned to either play *Word Blaster* (*n* = 30), *Dance Off!* (*n* = 30), or Spaceship Blaster (*n* = 30). Trained research assistants walked participants through instructions for each game beforehand. Participants were assigned to a two-minute practice period where they could become accustomed to the game's controls and ask questions if needed. After their practice round, participants were tasked to complete ten minutes of gameplay and try to score as many points as possible in their respective games. They were informed their scores would be recorded. After gameplay, participants completed the OSPAN and then the CPT (described below). All participants were debriefed and assigned their course credit before leaving.

Measures

Automated Operation Span (OSPAN) Task

After gameplay, participants completed the automated version of the Operation Span (OSPAN) task (Unsworth et al., 2005), a valid and reliable measure of working memory capacity. The OSPAN presents participants with a series of math problems (e.g., (1 X 2) = 1 = 96?) followed by target letters (e.g., L). Broadly, participants are instructed to read the math problem, determine whether the presented answer is True or False, then read the target letter. After a series of 3-7 math operations, participants are tested on their recall of the target letters in the order in which they were presented. Participants first had a period of practice for the letter span, then a practice period for the math portion, then a practice period of the letter recall and math portions simultaneously. Participants were encouraged to always keep their math accuracy at or above 85%. Letters were presented for 800 msec. Participants were instructed to complete this task independently at a desktop computer. The OSPAN lasts approximately 15-20 minutes.

The OSPAN reports five scores based on task performance. The first, OSPAN Total Score, is equal to the sum of all perfectly recalled letter sequences (i.e., sets). The second, Total Correct, is the total number of letters recalled in the correct position. The third score, Total Errors, is equal to the sum of all total errors on the math portion (Math Speed and Math

Accuracy Errors). Math Speed Errors were counted when the participant ran out of time in solving a given math equation, while Math Accuracy Errors determined how often the participant solved the math equation incorrectly.

Conners Continuous Performance Test

After completing the OSPAN, participants next completed the third version of Conners Continuous Performance Task (CPT-3; Conners, 2014), a valid and reliable measure of sustained attention. In the CPT-3, participants view a computer screen while black letters flash on a white background. Participants are instructed to respond as quickly as possible to each letter by left clicking the mouse button when a letter appears on their computer screen, other than the letter "X". When the letter "X" appears, participants are instructed to refrain from clicking the mouse. Letters are presented at variable rates of 1, 2, or 4 seconds. Participants completed this task independently at a desktop computer. They received a brief practice round before a scored round that lasted approximately 15-20 minutes.

Eight scores were collected from the CPT. First, Detectability reflects the ability to discriminate non-target (i.e., the letter "X") from target letters (i.e., all other letters). Second, Omissions were calculated as failures to respond to target letters (i.e., no response to a letter besides "X"). Third, Commissions were calculated as responses to a non-target letter (i.e., a response to the letter "X"). Fourth, Hit Reaction Time (HRT) was defined as the average speed of correct responses (i.e., a response to a letter besides "X") for the duration of the CPT administration. Fifth, Hit Reaction Time Standard Deviation (HRT SD) measured consistency in response speed during administration. Sixth, Hit Reaction Time Block Change (HRT BC) reflected the change in average response speed across administration blocks. Next, Hit Reaction Time Interstimulus Interval (HRT ISI) change was calculated to reflect the change in response speed across different interstimulus intervals (i.e., slower vs. quicker presentations of the letter "X"). Finally, Variability reflects the consistency in response speed during different segments of the CPT administration.

Study One Analytic Approach

All analyses were conducted using SPSS (IBM Corp., 2020). To examine bivariate associations between our video game scores and established measures of working memory and attention, Pearson correlation coefficients were computed between OSPAN scores, CPT scores, and our three video game scores. A single correlation matrix was computed; therefore, Bonferroni corrections were not applied. This analysis was in pursuit of Objective One.

Study Two

Participants

To meet Objectives 2 and 3 and test their accompanying hypotheses, subjects were recruited from the website Academic Prolific, an online research participant pool. The experiment consisted of a 2 (Heavy Drinkers vs. Non-Alcohol Drinkers) X 2 (alcohol vs. control stimuli) within-subjects design. Participant groups were defined using the following screening question: "How many units of alcohol do you drink on average per week?" Participants invited to participate in the study if they answered either "0" (non-alcohol drinkers; Alcohol Abstainer group) or "14+" (heavy drinkers; Heavy Drinking group) to the screener.

A total of 178 participants were invited to participate in the study. Fifteen (15) participants reported issues with the game's server at the time of their data collection and left the study before completing it. They were provided compensation but excluded from analysis, leaving a total sample size of 163. Participants were largely male (67%) and White (67%), with lesser individuals identifying as Hispanic (26%), Black (10%), Asian (3%), and Other (1%)

ethnicities. The average age of the sample was 30.4 years. See Results section for differences in demographic data between the Heavy Drinking and Alcohol Abstainer groups.

Procedure

Participants confirmed they were using a desktop or laptop computer with reliable audio and provided their informed consent prior to participation. After providing informed consent, participants were presented with a series of self-report questionnaires assessing aspects of alcohol use and potential moderators of the relationship between alcohol use and game experiences. Next, participants were redirected to the first video game. Instructions were provided over voice audio and screenshot. Gameplay lasted ten minutes. Afterwards, participants provided self-report ratings of their alcohol cravings, cue reactivity, alcohol-related thoughts, and perceptions of gameplay. Next, participants were redirected to the second and third video games, which also lasted ten minutes each and were followed by the self-report ratings. The order of *Spaceship Blaster*, *Word Blaster*, and *Dance Off!* was randomized for each participant. Whether participants played the alcohol (Experimental condition), or neutral (Control condition) version of the video games was randomized as well. The study lasted approximately 60 minutes and participants were credited $9 to their Prolific account in exchange for completing the study.

Measures

Demographics

The following demographic information was collected from participants: age, gender, and race/ethnicity. Participants were offered options of male, female, or other for gender. For race/ethnicity, participants chose between White, Black, Hispanic, Oriental/Asian, Asian Pacific Islander, Native American, or Other identities. Age was entered manually.

Alcohol Use Behaviors

Items assessing feelings about drinking to intoxication and feelings about driving a motor vehicle under the influence of alcohol were assessed using a 9-point Likert scale (*Completely Negative* to *Completely Positive*). Willingness to drink to the point of intoxication was assessed using a 9-point Likert scale (*Completely Unwilling* to *Completely Willing*). Past 30-day drinking was assessed using the item "*How many days in the last 30 have you had one or more drinks in a single sitting?*" Past 30-day binge drinking was assessed using the item "*How many days in the last 30 have you had four (women)/five (men) drinks in a single sitting?*" Average drinks per occasion was assessed using the item "*On a typical night when you drink alcohol, how many complete drinks do you have?"*

Alcohol Cue Reactivity

To measure alcohol cue reactivity, participants provided ratings of their emotions and alcohol cravings in response to three alcohol-related images: one picture of beer, one picture of red and white wine, and one picture of liquor. These images were chosen to capture a potential variety of different types of incentive salience to alcohol (for example, heavy drinkers strongly preferring beer over wine or liquor). This was paired with three neutral images: one picture of a water bottle, one picture of a pair of keys, and one picture of a ball. These images were chosen to capture a potential variety of stimuli with theoretically little-to-no incentive salience for alcohol. Water was included to provide a matching neutral stimulus based on the control versions of gameplay. These pictures were presented in the same order throughout gameplay for each condition.

These six images were presented, along with their accompanying ratings, before and after video gameplay. This format allowed for measuring cue reactivity baseline differences pre-test and changes post-test for each game (Limbrick-Oldfield et al., 2017). Participants were presented with images and were asked to rate whether each picture provoked 1) positive or negative emotions, and 2) strong or weak emotions on a 5-point Likert scale. Referencing each image, participants also answered two items: "*How much is this picture related to alcohol?*" and "*How strong is your urge/wish to drink alcohol?*" on a 10-point Likert scale (0 = *Not at All* to 10 = *Extremely*).

Participants also completed an 8-item Likert scale (Bohn et al., 1995) assessing their immediate alcohol cravings after each game. The scale used a 7-point format (-3 = *Strongly Disagree* to 3 = *Strongly Agree*). Example items include "*All I want to do now is have a drink*" and "*I want a drink so bad I can almost taste it.*"

In-Game Cognitions

Participants were asked to remember their experience during gameplay and rate how much they experienced certain thoughts related to alcohol. The Likert scale used a 10-point format (0 = *Not at All* to 10 = *Extremely*). Example items include "*How hard did you try not to think about alcohol?*" and "*How much did you feel like you needed an alcohol drink?*" Participants were also queried about non-alcohol related thoughts, such as "*I was thinking about schoolwork I have to do today*" and "*I was thinking about my social plans for later.*"

Virtual Transportation

Participants rated how transported they were into each video game with an 11-item scale (Burrows & Blanton, 2016). Sample items include "*I found myself temporarily lost in the game*," and "*I was concentrating on how I was performing during the game*." A 7-point Likert scale was used (0 = *Not at All* to 6 = *Extremely*).

Study Two Analytic Approach

For Objective Two, a Multiple Analysis of Covariance (MANCOVA) was conducted to examine 2 (Abstainers vs. Heavy Drinkers) X 2 (Control vs. Alcohol game conditions) group differences in three dependent variables: *Spaceship Blaster* scores, *Word Blaster* scores, and *Dance Off!* scores. Covariates were determined by preliminary chi-square and ANOVA analyses of demographic data.

For Objective Three, two mixed Analyses of Covariance (ANCOVA) were conducted to compare mean differences among two dependent variables representing alcohol cue reactivity. To create these variables, scores from items on our cue reactivity questionnaire related to emotion type (positive vs. negative), emotion valence (weak vs. strong), and urge for alcohol (none vs. extremely strong) were summed. Resulting scores represent alcohol cue reactivity on a spectrum from high (strong, positive emotions paired with drinking urges) to low (weak, negative emotions with no drinking urges). Two scores were created to represent alcohol cue reactivity in response to both alcohol imagery and neutral imagery and were treated as dependent variables.

Experimental condition (Abstainer, neutral games; Abstainer, alcohol games; Heavy Drinker, neutral games; Heavy Drinker, alcohol games) was entered as the between-subjects factor in the ANOVA. Time was the within-subjects factor: time points of cue reactivity repeated measurements were collected at baseline, after the first game, after the second game, and after the third game. Covariates were determined by the preliminary analyses.

CHAPTER III

RESULTS

Study One Results

Correlations between Game Scores and OSPAN/CPT Scores

Bivariate correlations between *Spaceship Blaster* scores, OSPAN scores, and CPT scores are presented in Table 1. *Spaceship Blaster* total scores (i.e., number of rings driven through) and armor scores (i.e., total amount of asteroids crashed into) were significantly positively correlated (r = .44, p < .05). A significant negative correlation (r = -.41, p < .05) was found between *Spaceship Blaster* total scores and CPT errors of omission (i.e., failures of response to target letters). No remaining significant correlations were revealed between Spaceship Blaster total/armor scores, CPT scores, and OSPAN scores.

Bivariate correlations between *Word Blaster* scores, and OSPAN/CPT scores are presented in Table 2. Accuracy scores for *Word Blaster* (i.e., percentage of letters typed correctly) were positively correlated with maximum combo scores (i.e., highest number of letters typed correctly without mistakes; r = .78, p < .01). Maximum combo scores were positively correlated with current combo scores (i.e., letters typed correctly without mistakes when game timer ends; r = .41, p < .05).

Concerning OSPAN scores, *Word Blaster* total scores were significantly and positively correlated with OSPAN total scores (i.e., sum of all perfectly recalled letter sequences; r = .63, p < .001) and OSPAN total correct (i.e., sum of all letters recalled in the correct position; r = .54, p < .01). *Word Blaster* current combo scores were negatively correlated with OSPAN total correct (r = -.51, p < .01).

Concerning CPT scores, *Word Blaster* total scores were negatively correlated with CPT Hit Reaction Time Block Change scores (i.e., the change in mean reaction speed across administration blocks; $r = -.37$, p < .05). *Word Blaster* accuracy scores were negatively correlated with CPT HRT Standard Deviation (i.e., the standard deviation of participants' average speed of correct responses; $r = -.41$, $p < .05$), HRT Interstimulus Interval (i.e., the change in mean response speed at various interstimulus intervals; $r = -.37$, $p < .05$), and Variability (i.e., consistency in response speed; $r = -.42$, $p < .05$) scores. No remaining significant correlations were revealed between *Word Blaster* scores, CPT scores, and OSPAN scores.

Bivariate correlations between *Dance Off!* scores, and OSPN/CPT scores are presented in Table 3. Total scores for *Dance Off!* were significantly negatively correlated with OSPAN math error scores (i.e., sum of all math speed and math accuracy errors; $r = -.39$, $p < .05$). No remaining significant correlations were revealed between *Dance Off!* scores, OSPAN scores, and CPT scores.

Study Two Results

Chi-Square/ANOVA Analyses for Group Differences in Pre-Game Data

Chi-square analyses examined 2x2 group differences in categorical data between our drinking (Alcohol Abstainer versus Heavy Drinker) and experimental condition (Control versus Alcohol stimuli) groups. ANOVAs examined group differences in mean scores for numerical data. Our results are presented in Table 4. There was a significant difference in age between groups ($F(160, 3) = 10.2$, $p < .01$), with the Abstainer group generally being younger (M_{age} = 25.3 years) than the Heavy Drinker group (M_{age} = 35.5 years). There was no significant difference in gender distribution between groups. There was a significant difference in race/ethnicity distribution between groups (χ^2 = 28.1(18), p < .01), with the Heavy Drinker group generally being comprised of more White individuals (79% White) than the Abstainer group (40% White).

Additionally, there were significant differences in mean past-month drinking days (F(163, 3) = 41.3, p <.01), mean past-month binge drinking (5+ alcohol servings) days (F(160, 3) = 22.5, p < .01), mean past-month drinking days beginning before 4:00 PM (F(160, 3) = 9.2, p <.01), and mean alcohol servings per drinking occasion (F(158, 3) = 28.8, p < .01) between groups. The Heavy Drinking group endorsed more past month drinking days ($M_{\text{drinking days}}$ = 13.6), more past month binge drinking days ($\text{M}_{\text{binge days}}$ = 7.2), more past month drinking days beginning before 4:00 PM ($M_{\text{days before 4:00 PM}}$ = 4.1), and more mean alcohol servings per typical drinking occasion (M_{drinks} = 6.0) than their Abstainer counterparts ($M_{\text{drinking days}}$ = 1.7, $M_{\text{binge days}}$ = 0.4, $M_{\text{days before 4:00 PM}}$ = 0.4, mean $_{\text{drinks}}$ = 2.3).

MANCOVA and T-Test Analyses for Group Differences in Game Scores

A Multiple Analysis of Covariance (MANCOVA) examined 2x2 group differences in our three different game scores. Since age and race/ethnicity differed significantly across groups in the preliminary analyses, they were included as covariates in the MANCOVA. These MANCOVA results are presented in Table 5. The overall model was not significant (*Pillai's Trace* = 0.07, F(414, 9) = 1.1, p = .36), as were individual results for *Spaceship Blaster* (F(143, 3) = 1.4, p = .24), *Word Blaster* (F(143, 3) = 1.7, p = .17), and *Dance Off!* (F(143, 3) = 0.1, p = .94).

However, comparison of group means showed certain trends in the hypothesized direction. Game performance for Heavy Drinkers in the Alcohol game condition group performed worst overall for both *Spaceship Blaster* ($M_{\text{Spaceship Blaster}}$ = 11.6) and *Word Blaster*

($M_{\text{Word Blaster}}$ = 852.6), followed by Heavy Drinkers in the Control game condition group ($M_{\text{Spaceship Baster}}$ = 15.0, $M_{\text{Word Blaster}}$ = 956.8). Alcohol Abstainers in both the Alcohol ($M_{\text{Spaceship Baster}}$ = 33.7, mean $_{\text{Word Blaster}}$ = 1126.5) and Control ($M_{\text{Spaceship Baster}}$ = 16.1, $M_{\text{Word Blaster}}$ = 1160.3) game conditions performed better. Given these trends, exploratory independent samples t-tests were conducted to examine group differences in scores between Heavy Drinkers and Abstainers, regardless of game condition. Results indicated a significant difference between groups for *Word Blaster* (t (157) = 2.5, p = .01), which survived a Bonferroni correction. Regardless of experimental condition, heavy drinkers had worse *Word Blaster* performance overall ($M_{\text{Word Blaster}}$ = 911.4) than alcohol abstainers ($M_{\text{Word Blaster}}$ = 1144.0). We note this finding was not originally hypothesized. T-test results were not significant for *Spaceship Blaster* (t(155) = 1.1, p = .27) or *Dance Off!* (t(150) = 0.5, p = .62).

Mixed ANCOVAS for Group Differences in Cue Reactivity over Time

First, a mixed ANCOVA examined group differences in mean cue reactivity in response to alcohol imagery across timepoints. Age and race/ethnicity were included as covariates. These results are presented in Table 6. Overall, mean cue reactivity scores to alcohol imagery did not differ significantly when considering the group x time interaction (*Pillai's Trace* = 0.10, F(9) = 1.5, p = .15). Tests of within-subjects effects were also not significant (F(9) = 1.76, p = .11), suggesting there were no meaningful differences in mean differences in cue reactivity over time. However, the test of between-subjects effects reached significance (F(3) = 20.1, p < .01), suggesting there were significant differences between conditions in their cue reactivity. Post-hoc pairwise comparisons suggest that average cue reactivity scores for Heavy Drinkers was significantly higher ($M_{\text{cue reactivity}}$ = 12.6) than scores for Alcohol Abstainers ($M_{\text{cue reactivity}}$ = -0.2), regardless of experimental condition (all ps <.01). These post-hoc comparisons passed

Bonferroni corrections. See Figure 4 for mean cue reactivity scores for alcohol imagery over time between experimental conditions.

A second mixed ANCOVA (with age and gender as covariates) examined group differences in mean cue reactivity in response to neutral imagery across timepoints. Results are presented in Table 7. Overall, mean cue reactivity scores to neutral imagery differed significantly when considering the group x time interaction (*Pillai's Trace* = 0.13, $F(9) = 2.0$, $p = .04$). The test of within-subjects effects was significant ($F(9) = 2.90$, $p = <.01$), indicating meaningful differences in cue reactivity scores over time. The test of between-subjects effects was also significant ($F(3) = 7.20$, $p = <.01$). Post-hoc pairwise comparisons indicate that, for Heavy Drinkers who played the alcohol game versions, their cue reactivity scores for neutral imagery decreased from baseline ($M_{\text{cue reactivity}} = 4.4$) to after Game 3 ($M_{\text{cue reactivity}} = 2.3$). Meanwhile, for Heavy Drinkers who played the neutral game versions, their cue reactivity scores for neutral imagery increased from baseline ($M_{\text{cue reactivity}} = 6.4$) to after Game 3 ($M_{\text{cue reactivity}} = 7.7$). These post-hoc comparisons passed Bonferroni corrections (all *CI*s 1.6 – 10.0). See Figure 5 for mean cue reactivity scores for neutral imagery over time between experimental conditions.

CHAPTER IV

DISCUSSION

The primary goals of this study were to examine the viability of video game interventions through a series of novel "gamified" cue reactivity paradigms for heavy alcohol drinkers. To pursue this examination, our objectives were threefold: 1) to test relationships between the novel games and established attention and working memory tasks, 2) test whether experimental manipulations of alcohol cue reactivity would create differences in game performance between heavy drinkers and a control population, and 3) examine differences in self-report cue reactivity after video game play between heavy drinkers and a control population. We hypothesized that game performance scores would positively correlate with scores of the tasks (Hypothesis 1). Next, we thought that heavy alcohol drinkers playing game versions with embedded alcohol cues would have the lowest scores for game performance among the experimental groups (Hypothesis 2). Last, we hypothesized heavy drinkers playing alcohol game versions would have the highest scores in their cue reactivity across the experiment between the different experimental groups (Hypothesis 3).

Study One Discussion

Results generally supported Hypothesis 1. Total scores for *Spaceship Blaster* were moderately and negatively correlated with CPT errors of omission, meaning that participants who performed better on *Spaceship Blaster* generally made fewer errors related to "missing" a CPT response when it was required. The CPT is a widely used assessment used to measure attention across a variety of clinical presentations (Ord et al., 2021), including alcohol addiction (Dougherty et al., 1999). Omission errors have been theorized to reflect the ability to sustain one's attention (Conners, 2014); meaning when more omissions occur, attentional lapses are theoretically occurring as well. *Spaceship Blaster* Total scores represented the ability of participants to pilot their spaceship through rings embedded within the game's asteroid field. We theorized point scoring in this game would require sustained attention of the asteroid field and CPT results appear to support this viewpoint.

In contrast to *Spaceship Blaster* requiring attentional components, *Word Blaster* was theorized to require working memory components. Several scores from *Word Blaster* were moderately and positively correlated with OSPAN total scores and OSPAN total correct, suggesting that participants who performed better on *Word Blaster* generally recalled more letter sets (e.g., 3 letters in a set of 3) and more correctly positioned letters overall on the OSPAN. The OSPAN is a widely used measure of working memory capacity, a construct theorized to be a cognitive system responsible for maintaining information in the face of ongoing processing or distraction (Conway et al., 2005). It has been used in alcohol-related clinical applications in prior research (Rowland et al., 2021; Salemink & Wiers, 2014). Total scores for *Word Blaster* represent the ability for participants to correctly hold a given word in memory and type it out in the face of in-game distractions like floating orbs, changing background environments, and other words on the screen. OSPAN results indicate this gaming process required a moderate amount working memory.

In addition, *Word Blaster* scores were negatively correlated with scores from the CPT, including Variability scores and several Hit Reaction Time scores, specifically Block Change, Standard Deviation, and Interstimulus Interval HRT scores. Generally, higher CPT HRT/Variability scores reflect inconsistent and irregular reaction times to stimuli (i.e., pressing the letter "X" both quickly and slowly across the task; Conners, 2014). This means that participants who performed well on *Word Blaster* also tended to perform more consistently on the CPT, with less inconsistency and less variability in their responses across blocks and interstimulus intervals. Overall, these results suggest that those who scored higher on *Word Blaster* also performed better on both the OSPAN and the CPT, displaying both sustained attention and stronger capacities for short-term mental manipulation. Working memory and attention have been theorized to underlie a more generalized factor of cognitive control (Engle & Kane, 2004), suggesting *Word Blaster* performance specifically may measure a cognitive style reflective of deliberate, sustained processing in the face of multiple competing stimuli.

Scores for *Dance Off!* were in support of Hypothesis 1 as well. Namely, *Dance Off!* total scores were moderately and negatively correlated with OSPAN Total Error scores, meaning that participants who performed well on this game also tended have less math computation errors related to running out of time and/or solving simple math problems incorrectly under a time limit. Both *Dance Off!* and the OSPAN presented participants with to-be-remembered items for a short period, reflecting how the cognitive load of working memory tasks are thought to represent a function of the proportion of time during which they capture attention (Barrouillet et al., 2007). Thus, both tasks perhaps measure participants' ability to effectively process information presented for short periods (i.e., OSPAN math equations and *Dance Off!* letter sequences) before working memory's time decay takes hold. This time delay reflects perhaps the most critical process and major limitation to working memory (Barrouillet & Camos, 2012), and a critical component to capture.

Collectively, these significant correlations suggest that our three games capture different aspects of cognitive control, specifically consistency in attention, attentional lapses, and working memory. When these games were manipulated using embedded alcohol images in Study Two to increase alcohol cue reactivity, players were required to use these aspects of cognitive control in the face of the symptoms of cue reactivity that result- namely, the symbolic-expressive (craving, motivation) and behavioral (theoretical alcohol-seeking, in-game points) symptoms theorized by Drummond (2000).

Study Two Discussion

Regarding Hypothesis 2, results were not supported. Although there were trends in the hypothesized direction, such that heavy drinkers playing the alcohol versions of each game scored the least number of points on *Spaceship Blaster* and *Word Blaster*, these differences were not statistically significant when compared to the other three experimental groups. These findings could reflect how our Study 2 data collection procedures were moved to the Prolific online format because of the COVID-19 pandemic. While some research has cited that behavioral data collected from online crowdsourced research websites (i.e., Academic Prolific) is nearly indistinguishable from data collected in physical lab locations (Adams et al., 2020; Casler et al., 2013), others report more mixed results, depending on the tasks deployed (Crump et al., 2013; Sauter et al., 2020), or in-lab results producing more valid data with less noisy measurement (Segen et al., 2021; Gupta et al., 2021).

Given the games were originally designed to be played in-lab at a desktop computer, future work may support Hypothesis 2 if completed an in-person setting. As opposed to Study 1, in Study 2 we could not observe our participants gameplay directly, clarify or repeat game instructions for them, or confirm they were completing the study with minimal distraction. Also, messages received through the Prolific website indicated some issues with the study’s web server for certain players at the time data collection was opened, leading to slower and/or “glitchy” gameplay for some players. Because of this issue, data collection was re-opened for approximately 15 players, most of whom were in the Heavy Drinker, alcohol gaming group.

These combined issues perhaps lead to more ‘noisy’ data for certain players, resulting in a failure to reject the null hypothesis for *Spaceship Blaster* and *Word Blaster*. For *Dance Off!*, it generally may have also been a harder game to pick up for players, as the modal score for this game was zero (0). These issues may have contributed to *Dance Off!* scores being too similar across experimental groups. Future work could spend more time beta-testing *Dance Off!* or lowering the game’s difficulty level to ensure greater variance in scores.

Even though Hypothesis 2 was not supported, post-hoc findings comparing participant groups were in line with theory: overall, Heavy Drinkers scored worse on *Word Blaster* compared to Abstainers. Previous studies have found that those drinking alcohol repeatedly at clinically significant levels perform worse on several in-lab measures of attention and/or working memory (Crego et al., 2009; Gunn et al., 2018; Maillard et al., 2020). Our results show that incorporating gaming elements into remotely deployed versions of these tasks does not limit their ability to detect cognitive deficits for heavy drinking populations.

Attention and working memory are critical components of cognitive control, a concept defined as an internal mental representation, maintenance, and updating of information in the service of exerting control over one’s thoughts and behavior (Wilcox et al., 2014). Alcohol Use Disorders (and other addictions/impulse control disorders) are largely characterized by a loss of cognitive control, leading to symptoms like drinking despite negative consequences, drinking more or longer than intended, or being unable to cut back (American Psychiatric Association, 2013). Although a relatively young field of research, some “gamified” tasks designed to strengthen different aspects of cognitive control have shown preliminary efficacy in reducing relevant addiction phenomena such as cravings and cognitive biases (Boendermaker et al., 2017; Cox et al., 2015; Kerst & Waters, 2014; Manning et al., 2021).

Our results suggest that *Word Blaster* performed best as a pure measure of cognitive control deficits in heavy drinkers, compared to the other two games. This reflects how repeated exposure to alcohol can decrease attention and working memory control over time or, simultaneously, how deficits in these cognitive areas can serve as a risk factor for AUD (Gunn et al., 2018; Le Berre et al., 2017; Maillard et al., 2020). Future research should examine the effects of heavy drinkers playing *Word Blaster* over time. Specifically, determining whether improvements in their game scores correlate to meaningful improvements in cognitive and behavioral control over alcohol-related stimuli. This would represent a novel "gamified" approach to AUD intervention adjunct that could be acceptable, feasible, and well-tolerated among heavy drinking populations.

Results were mixed regarding Hypothesis 3. When considering cue reactivity towards pure alcohol imagery, our results suggested that mean cue reactivity scores were not highest in the Heavy Drinker, alcohol games experimental group pre- to post-experiment. Meaning, despite our experimental induction, self-reported strong positive emotions and cravings were not meaningfully different over three rounds of gameplay for this group, compared to their baseline scores. Rather, between-groups results showed difference in mean cue reactivity scores for alcohol stimuli between Heavy Drinker and Abstainer groups; meaning, self-reported strong positive emotions and cravings for alcohol were higher in Heavy Drinkers (compared to Abstainers), irrespective of the types of stimuli embedded within the games.

While perhaps puzzling on the surface, this finding essentially replicates the general cue reactivity paradigm for alcohol (Carter & Tiffany, 1999; Drummond, 2000; Niaura et al., 1988), in that alcohol-related stimuli likely take on incentive salience for heavy drinkers and elicit strong emotions and/or cravings. Our findings extend this literature by suggesting that “gamified” alcohol cue exposures specifically did not reliably raise or reduce cue reactivity for alcohol across timepoints in our experiment. Another interesting interpretation of this finding is that virtual games designed to tax the limited cognitive control resources did not appear to reliably interfere with the cue reactivity process over a roughly one-hour time period. Additionally, a recent study documented no differences between alcohol and water cue types on subjective cravings for alcohol in laboratory setting among patients with AUD (Venegas & Ray, 2020), suggesting that our finding is not a major outlier within the literature.

Our finding is perhaps best understood keeping in mind the context Study 2, which was a roughly one-hour experiment completed online, which contained three 10-minute series of “gamified” cue exposures. Previous successful cue exposure treatment paradigms for alcohol, in which alcohol cues are repeatedly presented to reduce cravings/motivations to drink over time, have taken anywhere from 6-12 sessions for inhibitory and/or extinction learning to reliably take effect (Conklin & Tiffany, 2002). More time then, over repeated sessions in a true treatment format, may have reduced alcohol cue reactivity for the hypothesized experimental group.

However, when considering cue reactivity towards neutral imagery, our results suggested support for Hypothesis 3. Heavy Drinkers in the alcohol game condition had significant decreases in their cue reactivity scores for neutral imagery from baseline to post-test. On the opposite hand, for Heavy Drinkers in the neutral game condition, their cue reactivity scores for neutral imagery increased from baseline to post-test. Essentially, our experimental induction appeared to have opposing effects, in that cue reactivity for neutral stimuli increased among the neutral (water cues) condition, but decreased in the alcohol condition, as hypothesized.

This finding, a novel addition to the cue exposure treatment literature, shows that cue reactivity 1) can be elicited by non-alcohol related imagery, and 2) can decrease significantly in as little as three sessions of "gamified" alcohol cue exposure. Prior research has indicated that non-drug related neutral cues can evoke strong subjective responses for one's drug of choice in both lab and virtual reality-based cue exposure paradigms (e.g., Conklin et al., 2008; Traylor et al., 2009). To our knowledge, our finding is the first to exhibit such a reduction among heavy drinkers exposed to alcohol cue reactivity in a series of games requiring different aspects of cognitive control.

Follow up research should replicate these results and examine if changes in cue reactivity for alcohol-related images and associated drinking behaviors similarly decrease. Treatment studies delivering several cue exposure sessions through virtual reality and "serious" video games have shown some preliminary efficacy when taking place over timeframes of four to eight weeks (Lee et al., 2007; Lee et al., 2009; Metcalf et al., 2018). Such studies tend to include such paradigms as adjuncts to treatments with more robust evidence bases for their effectiveness, like cognitive behavioral therapy, motivational interviewing, or family therapy (National Collaborating Centre for Mental Health, 2011). Future work could use this adjunct approach as well, reducing alcohol cue exposure may need several types of treatment approaches (e.g., cognitive, behavioral, pharmacological, etc.).

General Discussion

Overall, with caveat, the results of these studies suggest that video game interventions have potential to measure and successfully reduce one form of alcohol cue reactivity. *Word Blaster* perhaps displayed the most potential in this regard, since it correlated with several measurements of attention/working memory; simultaneously, a sample of Heavy Drinkers scored significantly poorly on it. Prior research has documented that cognitive control can be measured using game-based assessments (Ferreira-Brito et al., 2019; Song et al., 2020); to our knowledge, our study is the first to extend game-based assessment of cognitive control to Heavy Drinkers specifically.

Our results also suggest that alcohol cue reactivity in response to neutral images can be significantly decreased in Heavy Drinkers within three sessions of gamified exposure; importantly, this pattern was not replicated for alcohol images, likely the more important type of cue to target. Cue exposure therapy works by repeatedly exposing an individual with a SUD to stimuli associated with their addictive drug of choice (e.g., people, places, or things associated with drugs) ***without*** drug administration. Repeated exposure to these stimuli, or "cues," in this fashion should theoretically eliminate the Pavlovian condition response through extinction and/or inhibitory learning (e.g., drug cravings and associated motivational states; Havermans & Jansen, 2003). Inhibitory learning is when an individual learns that a conditioned stimulus (CS; e.g., alcohol stimuli) no longer reliably predicts the unconditioned stimulus (US; e.g., receipt of alcohol), essentially "overriding" the original CS-US association. Inhibitory learning is perhaps the most critical process in exposure therapy (Craske et al., 2014), but one that is slower to develop in those with AUD specifically (Buckfield et al., 2021). Thus, future research should test the *Word Blaster* game specifically to reduce the effects of alcohol cue reactivity in exposures over a longer timeframe, such as four to eight weeks of repeated play.

Nonetheless, evidence of heightened cue reactivity for alcohol images was present in the Heavy Drinkers who played the alcohol game versions. As seen in Figure 1, this was the only condition in which cue reactivity *increased* between baseline and Game 1 performance, although this effect was not maintained across performance of the entire study administration. Nonetheless, this suggests preliminary evidence that the alcohol cue reactivity paradigm can be successfully replicated within novel virtual gaming worlds. Future research should replicate this effect and examine the ability of virtual games to be an efficacious form of treatment delivery for alcohol cue exposure therapy.

Taken together, these findings suggest that our games not only require attentional and working memory components (at some level) to succeed but can be simultaneously embedded with stimuli to manipulate alcohol cue reactivity in heavy drinkers. Although increased cue reactivity and decreased attention/working memory scores would likely correlate, meaning that an increase in salience of alcohol cues would relate to a decrease in cognitive control, that relationship was not examined between Study One and Study Two. Rather, we chose to have participants exert cognitive effort in the presence of salient stimuli. The goal of cognitive bias modification tasks is to shift bias away from drug cues, decreasing cue reactivity and/or increasing the ability to exert cognitive control in the presence of such cues (Mayer et al., 2020). These games, therefore, may represent the beginning stages of a serious game-like take on such interventions.

Alternative explanations for our results may exist as well. It is possible that repetition of the cue presentations was responsible for a reduction in their liking through habituation, rather than effects of the gaming sessions themselves. Habituation learning would suggest that tonic craving to alcohol cues would decrease as a function of how often and/or how long they were presented; this type of learning may specifically relate to reduced emotional reactivity in repeated alcohol exposure, as opposed to effects from self-control-related thoughts and behaviors (Byrne et al., 2019). Also, the eventual reductions in cue reactivity could have been explained in part by reductions in impulsive cognition, rather than the effects of cue reactivity or our experimental manipulation. Bickel et al. (2020) has suggested that working memory training, for instance, may strengthen cognitive systems involved in self-regulation and considering future consequences more often. Theoretically, this might have led to our cues losing their incentive salience over time, reflected through weaker cravings and emotional/motivational states for alcohol seeking.

Limitations

This study should be interpreted considering its limitations. First, COVID-19 necessitated running part of this study online. Therefore, observing whether participants were actively invested in their game performance was not possible. However, Academic Prolific, the crowdsourced online subject pool used for Study 2, has been shown to generally have a seasoned participants which produce high-quality data compared to other platforms (Palan & Schitter, 2018; Peer et al., 2021). Second, we were not able to recruit a pure sample of Abstainers, or those who consume no alcohol whatsoever. For example, despite answering the initial screener item “How many units of alcohol do you drink on average per week?” with responses of zero (0), some participants endorsed minor amounts of past month drinking in follow-up questionnaires (1.7 mean past-month drinking days, 0.37 mean past-month binge drinking days). Although we found meaningful differences in our groups that allowed us to test associated hypotheses, future studies would benefit from stricter methods of recruitment, such as multiple alcohol-related screening items. Third, some dropout occurred over the course of Study 2. Approximately 8% (n = 15) of participants discontinued the study before reaching the final game, requiring re-recruitment to reach the n = 160 sample size required theoretically to detect the hypothesized effect. Although certainly not new to the field of experimental online data collection (Arechar et al., 2018; Hoerger, 2010), this may have influenced some of our null results. Last, we did not pilot test the images used as measures of cue reactivity to determine their incentive salience. Although we attempted to capture the spectrum of incentive salience using images representing a variety of commonly consumed alcoholic drinks and accompanying neutral images, we cannot say for certain. Future work should incorporate pilot testing into study design first to make certain that differences in cue reactivity present in response to the specific images used, perhaps using a wider variety of stimuli.

Conclusions

In conclusion, our study found that laboratory administrations of our three video games were correlated with established measures of attention and working memory. Online administrations of these video games resulted in worse in-game performance for *Word Blaster* among a Heavy Drinking sample. An experimental induction approach, in the spirit of cue exposure therapy, resulted in 1) heightened cue reactivity for alcohol images in the Heavy Drinking sample that played game versions designed to heighten cue reactivity, and 2) decreased cue reactivity for neutral imagery over time in that same sample. Future work should examine in-person gameplay over a longer period in order to examine whether *Word Blaster* or other games can function as an effective means for gamified cue exposure therapy in heavy drinking populations.

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APPENDIX A

Table 1 Correlations between *Spaceship Blaster*, OSPAN, and CPT scores

	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. SB Total Score	**.44***	.24	.30	-.21	-.20	-.12	-.22	**-.41***	.02	.17	-.32	.10	-.12	.09	.02
2. SB Armor Score		-.33	-.26	.14	.05	.14	.00	-.24	.07	.23	-.35	.08	-.08	.00	.06
3. OS Total Score			**.90***	**-.25***	-.15	**-.26***	-.05	.07	-.06	-.04	-.05	.04	.00	.06	-.01
4. OS Total Correct				**-.38***	-.30	-.27	-.09	.02	-.10	-.06	.01	.08	.03	.04	.02
5. OS Math Errors					**.89***	**.55***	.13	-.05	**.22***	.08	-.09	-.02	-.05	-.05	-.05
6. OS Math Speed Errors						.10	.13	-.06	**.24***	.04	-.07	.01	-.13	.02	-.05
7. OS Math Accuracy Errors							.03	.00	.04	.08	-.06	-.06	.13	-.14	.00
8. CPT Detectability								**.55***	**.86***	**.60***	**-.38***	**.39***	-.08	-.01	**.54***
9. CPT Omissions									.17	.32*	.12	**.46***	.20	.10	**.62***
10. CPT Comissions										**.48***	**-.48***	.19	-.18	-.11	**.31***
11. CPT Preservations											**-.23***	**.38***	-.16	-.02	**.59***
12. CPT HRT												**.29***	**.28***	.19	.09
13. CPT HRTSD													.04	**.64***	**.70***
14. CPT HRTBC														-.18	-.02
15. CPT HRT ISI															.16
16. CPT Variability															

Note: Filled portions highlight correlations of interest. **Bolded** values with asterisks (*****) indicate significance at the p <.05 level

Table 2 Correlations between *Word Blaster*, OSPAN, and CPT scores

	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
1. WB Total Score	.08	.18	-.30	**.63***	**.54***	-.08	-.04	-.15	-.23	-.07	-.27	-.13	-.05	-.05	**-.37***	-.03	-.21
2. WB Accuracy		**.78***	.35	-.03	-.14	.27	.22	.24	-.24	-.29	-.08	.01	-.20	**-.41***	-.06	**-.37***	**-.42***
3. WB Max Combo			**.41***	.16	.02	.23	.28	-.11	-.04	-.20	.11	-.04	-.31	-.24	-.11	-.29	-.35
4. WB Current Combo				-.20	**-.51***	.33	.37	-.04	-.02	-.24	.23	-.15	-.06	-.28	.00	-.15	-.34
5. OS Total Score					**.90***	**-.25***	-.15	**-.26***	-.05	.07	-.06	-.04	-.05	.04	.00	.06	-.01
6. OS Total Correct						**-.38***	**-.30***	-.27*	-.09	.02	-.10	-.06	.01	.08	.03	.04	.02
7. OS Math Errors							**.89***	**.55***	.13	-.05	**.22***	.07	-.09	-.02	-.05	-.05	-.05
8. OS Math Speed Errors								.10	.13	-.06	**.24***	.04	-.07	.01	-.13	.02	-.05
9. OS Math Accuracy Errors									.03	.00	.04	.08	-.06	-.06	.13	-.14	.00
10. CPT Detectability										**.55***	**.86***	**.60***	**-.38***	**.39***	-.08	-.01	**.54***
11. CPT Omissions											.17	**.32***	.12	**.46***	.20	.10	**.62***
12. CPT Commissions												**.49***	**-.48***	.19	-.18	-.11	**.31***
13. CPT Preservations													**-.23***	**.38***	-.16	-.02	**.59***
14. CPT HRT														**.29***	**.26***	.19	.09
15. CPT HRT SD															.04	**.64***	**.70***
16. CPT HRT BC																-.18	-.02
17. CPT HRT ISI																	.16
18. CPT Variability																	

Note: Filled portions highlight correlations of interest. **Bolded** values with asterisks (*****) indicate significance at the p <.05 level

Table 3 Correlations between *Dance Off!*, OSPAN, and CPT scores

	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1. DG Total Score	.03	.04	**-.39***	-.29	-.32	.02	.04	-.13	-.18	.24	.13	.07	.22	.19
2. OS Total Score		**.90***	**-.25***	-.15	**-.26***	-.05	.07	-.06	-.04	-.05	.04	.00	.06	-.01
3. OS Total Correct			**-.38***	**-.30***	-.27*	-.09	.02	-.10	-.06	.01	.08	.03	.04	.02
4. OS Math Errors				**.89***	**.55***	.13	-.05	**.22***	.07	-.09	-.02	-.05	-.05	-.05
5. OS Math Speed Errors					.10	.13	-.06	**.24***	.04	-.07	.01	-.13	.02	-.05
6. OS Math Accuracy Errors						.03	.00	.04	.08	-.06	-.06	.13	-.14	.00
7. CPT Detectability							**.55***	**.86***	**.60***	**-.38***	**.39***	-.08	-.01	**.54***
8. CPT Omissions								.17	**.32***	.12	**.46***	.20	.10	**.62***
9. CPT Commissions									**.49***	**-.48***	.19	-.18	-.11	**.31***
10. CPT Preservations										**-.23***	**.38***	-.16	-.02	**.59***
11. CPT HRT											**.29***	**.26***	.19	.09
12. CPT HRT SD												.04	**.64***	**.70***
13. CPT HRT BC													-.18	-.02
14. CPT HRT ISI														.16
15. CPT Variability														

Note: Filled portions highlight correlations of interest. **Bolded** values with asterisks (*****) indicate significance at the *p* <.05 level

Table 4 Demographics and Alcohol Use between Group X Experimental Conditions

	Abstainer Group *n* = 81 Game Condition		Heavy Drinker Group *n* = 82 Game Condition			
	Control *n* = 42	Alcohol *n* = 39	Control *n* = 46	Alcohol *n* = 37	Test Statistic (*df*)	*p* value
Mean Age (SD)	27.1 (9.8)	24.2 (6.3)	33.1 (14.1)	37.1 (12.2)	F = 10.2 (*160*, *3*)	**<.01***
Gender					χ^2 = 3.3 (*3*)	.32
Female	16	16	11	11		
Male	26	23	35	26		
Race/Ethnicity					χ^2 = 28.1 (*18*)	**<.01***
White	16	17	39	26		
Hispanic	19	13	4	6		
Black	5	5	2	5		
Oriental/Asian	1	2	1	1		
Other	0	2	0	0		
Mean Past-Month Drinking Days (SD)	1.9 (2.3)	1.5 (2.0)	12.8 (9.6)	14.3 (8.9)	F = 41.3 (*161*, *3*)	**<.01***
Mean Past-Month Binge Drinking (5+) Days (SD)	0.7 (1.9)	0.03 (0.2)	7.8 (8.8)	6.5 (5.0)	F = 22.5 (*160*, *3*)	**<.01***
Mean Past-Month Drinking Days Before 4:00PM	0.5 (1.6)	0.2 (0.5)	3.5 (6.3)	4.7 (6.5)	F = 9.2 (*159*, *3*)	**<.01***
Typical Drinks on an Occasion (SD)	2.5 (2.2)	2.1 (2.4)	5.9 (2.9)	6.1 (2.9)	F = 28.8 (*158*, *3*)	**<.01***

Note: SD = standard deviation, *df* = degrees of freedom. **Bolded** values with asterisks (*) indicate significance at the p <.05 level.

Table 5 Game performance between Group X Experimental Conditions

	Abstainer Group		Heavy Drinker Group			
	Game Condition		***Game Condition***			
	Control	Alcohol	Control	Alcohol	*F (df)*	*p* value
Mean *Spaceship Blaster* score (SD)	16.1 (9.9)	12.5 (10.0)	15.0 (9.3)	11.6 (8.5)	1.4 (143,3)	.24
Mean *Word Blaster* score (SD)	1160.3 (568.2)	1147.6 (701.4)	956.8 (559.2)	852.6 (426.8)	1.7 (143,3)	.17
Mean *Dance Off!* score (SD)	28.5 (136.0)	28.8 (83.2)	20.0 (65.2)	22.4 (78.7)	0.1 (143, 3)	.94

Note: SD = standard deviation, *df* = degrees of freedom.

Table 6 Differences in Cue Reactivity to Alcohol Imagery across Timepoints

	Abstainer Group		**Heavy Drinker Group**			
	Game Condition		***Game Condition***			
	Control	Alcohol	Control	Alcohol	*F* (*df*)	*p* value
Mean Cue Reactivity Scores (SE)						
Baseline	0.65 (1.5)	-0.87 (1.6)	13.97 (1.6)	12.28 (1.7)		
After Game 1	0.89 (1.5)	-0.57 (1.6)	12.98 (1.6)	11.67 (1.7)		
After Game 2	0.01 (1.7)	-0.17 (1.8)	14.96 (1.8)	10.73 (1.9)		
After Game 3	-1.18 (1.6)	-0.33 (1.7)	14.44 (1.7)	10.01 (1.8)		
Within-Subjects Effects (Time)					*F* = 1.76 (*9*)	.11
Between-Subjects Effects (Conditions)					*F* = 20.1 (3)	**<.01***
Time X Condition					*F = 1.5* (9)	.15

Note: SE = standard error, *df* = degrees of freedom. **Bolded** values with asterisks (*****) indicate significance at the *p* <.05 level.

Table 7 Differences in Cue Reactivity to Neutral Imagery across Timepoints

	Abstainer Group		Heavy Drinker Group			
	Game Condition		***Game Condition***			
	Control	Alcohol	Control	Alcohol	*F* (*df*)	*p* value
Mean Cue Reactivity Scores (SE)						
Baseline	1.12 (0.9)	1.6 (1.0)	6.4 (1.0)	4.5 (1.1)		
After Game 1	1.20 (0.9)	1.3 (1.1)	7.4 (1.0)	3.9 (1.1)		
After Game 2	0.96 (1.1)	1.2 (1.1)	7.1 (1.1)	2.2 (1.2)		
After Game 3	0.70 (1.1)	2.2 (1.1)	7.7 (1.1)	2.3 (1.2)		
Within-Subjects Effects (Time)					*F* = 2.9 (*9*)	**<.01***
Between-Subjects Effects (Conditions)					*F* = 7.2 (3)	**<.01***
Time X Condition					*F* = 2.0 (9)	**.04***

Note: SE = standard error, *df* = degrees of freedom. **Bolded** values with asterisks (*****) indicate significance at the *p* <.05 level.

Figure 4 Cue Reactivity Scores for Alcohol Imagery over Time between Experimental Conditions

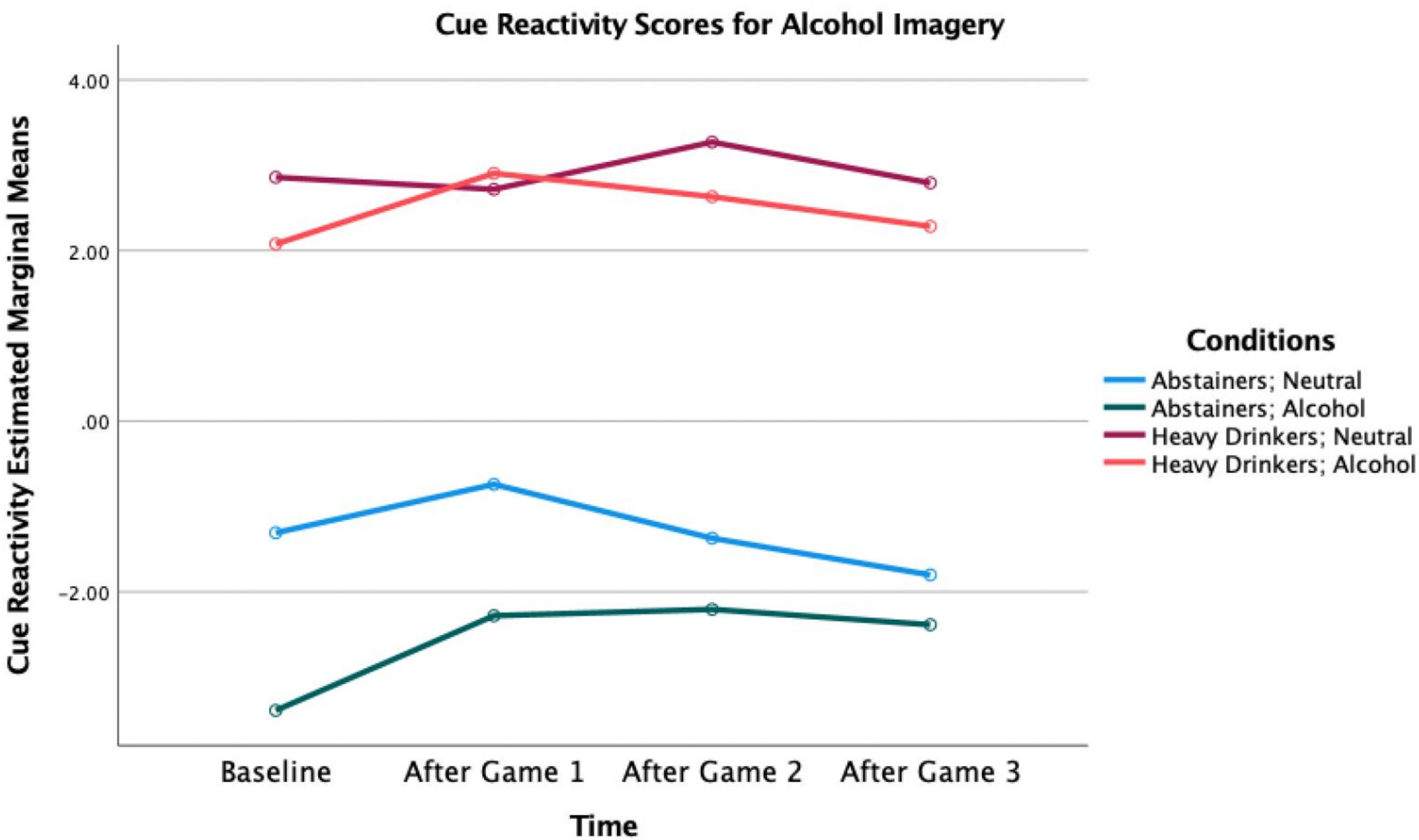

Figure 5 Cue Reactivity scores for Neutral Imagery over Time between Experimental Conditions