Virtual Reality Cue Exposure Therapy System

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ABSTRACT

Cue exposure therapy (CET) in the context of drug abuse rehabilitation refers to the manualized and repeated exposure to drug related cues, aimed at reducing the cue reactivity by extinction.

Conventionally, incarcerated drug abusers in rehabilitation in the Singapore Prison Service (SPS) undergo talk therapy and role play in group-based rehabilitation programmes based on the Cognitive Behavioural Therapy (CBT) principles. However, these methods lack realism and challenges were reported in managing cravings to drug cues and triggers in the naturalistic environment.

In collaboration with the SPS Correctional Research Branch of the Psychological & Correctional Rehabilitation Division, a prototype Virtual Reality (VR) immersive technology to desensitize drug abusers to different cues in drug use based on CBT principles has been developed and trialed.

Realistic drug-related encounters are simulated in a VR environment involving scenarios where a drug abuser might be tempted with illicit substances. This enables prison psychologists to provide immersive CET sessions where drug abusers are exposed to highly vivid and compelling drug cues and triggers to treat their drug craving.

Eye tracking and heart rate data of the VR User are monitored in real time during the VR experience. These heart rate and eye tracking data collected would enable the prison psychologist to determine if the subject is affected or overly fixated upon certain cues in the VR scenario. Drug abusers undergoing rehabilitation are essentially immersed in this controlled and safe VR environment with constant monitoring. With repeated sessions it is envisioned that they will develop effective coping mechanisms thus reducing recidivism amongst drug abusers.

Based on the user trial results and empirical data of the VR cue exposure therapy prototype system, we were able to demonstrate its effectiveness and efficacy in desensitizing drug abusers to different cues in drug use using CBT principles leveraging on state-of-the-art VR immersive technologies.

ABOUT THE AUTHORS

Derek Chong currently holds the appointment of Lead Engineer, Human Factors and Simulation Centre of Expertise (HFS COE) of the Home Team Science and Technology Agency (HTX). Under the research and innovation charter of the modelling and simulation pillar, Derek researches and implements leading-edge technologies in modelling, simulation and human performance analytics to digitize, augment and measure the human factors and performance sphere of training and operations in close collaboration with the various Home Team Departments.

Dr Saravana Kumar obtained his PhD in Electrical and Computer Engineering from the National University of Singapore (NUS) and has held various research positions at NUS, Agency for Science, Technology & Research (A*STAR) and the Ministry of Home Affairs. He is currently a Deputy Director for Modelling & Simulation at the Human Factors & Simulation Centre of Expertise (HFS CoE) from the Home Team Science & Technology Agency. Dr Saravana spearheads key research initiatives in the areas of extended reality, serious games, high fidelity simulators and constructive simulation to enhance operational performance and to comprehensively address workload, fatigue and vigilance issues faced by Home Team officers. He also partners with academia,

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Terence Teng is a specialist in the field of training simulation and Extended Reality technology with more than ten years of experience working alongside government units and members of the industry to develop training simulation system. He is currently a Lead Engineer for Modelling & Simulation at the Human Factors & Simulation Centre of Expertise (HFS CoE) from the Home Team Science & Technology Agency where he is actively involved in the conceptualization and management of training simulation projects in the Extended Reality domain.

Ying Meng Fai is the Director, Human Factors and Simulation Centre of Expertise (HFS COE) of the Home Team Science and Technology Agency (HTX). He leads the HTX Human Factors & Simulation (HFS) Centre of Expertise in research and development strategy and direction, drives significant HFS programs and projects to ensure achievement of valuable technical outcomes to augment human performance and safeguard the safety of the Home Team officers.

Renee Li is a psychologist in the Correctional Research Branch of Singapore Prison Services. She works on various projects with the overarching objective of enhancing rehabilitation efforts in SPS. Key projects include the use of virtual reality as a form of intervention by tapping on the synergy between psychology and technology. She contributed to the review and editing of the Psychological Perspectives section.

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INTRODUCTION

Drug craving is defined as a strong impetus or desire to use substances and is generally viewed as a central feature of addiction (Sayette et al., 2000; Tiffany, 1990). In this regard, Cue Exposure Therapy (CET) is a behavioristic psychological approach to treating substance use disorders (SUD) whereby individuals are exposed to relevant drug cues to extinguish conditioned responses (Mellentin, Angelina I. et al, 2017).

Virtual Reality (VR) cue exposure therapy technology has been applied for treating different mental disorders and has been proven to be an effective treatment method that can provide a positive and long-lasting impact on participants. The benefits include the ability to customise individual exposure to effectively reduce desire for drug use. Users are in a controlled and safe environment during practice with constant monitoring; and as users grow accustomed to the therapy sessions, their interactions, engagement and acceptance increases positively. Through this pilot research study, HTX and SPS aims to significantly enhance the level of realism experienced by the drug abuser inmates (i.e. subjects) via the use of virtual reality technology to more effectively trigger the drug craving effect in them.

The trials conducted were sub-divided into 2 phases: Phase 1 focused primarily on the engineering and system evaluation aspects of the research study which encompasses the interaction and usability of the virtual reality system as well as the system's design and performance parameters, namely the virtual reality headset's sensors' (heart rate and eye gaze) accuracy and the sensors' data capture. The trial was conducted with the Prison psychologists, counsellors and researchers. Phase 2 trial focused on the subjects' responses to the VR Cue Exposure Therapy during their allocated counselling and rehabilitation sessions with the Prison counsellors. The Phase 2 research trials also studied the effectiveness and efficacy of the VR Cue Exposure Therapy system deployed in tandem with the conventional Cognitive Behaviour Therapy (CBT) administered to the subjects during the final leg of their incarceration.

This paper begins by describing the conventional Cognitive Behavioural Therapy (CBT) method administered by the SPS psychologists to the subjects and its limitations. Next it discusses the overview of the VR Cue Exposure Therapy system including the respective hardware and software components. The system performance and usability are described in the subsequent section. Following this, data from the trial sessions are analyzed and the insights gained on the VR system's therapeutic efficacy are discussed. Finally, the paper discusses the next steps in terms of the system's technological development and research, as well as applications in other use cases in SPS' cue exposure therapy rehabilitation program to bring its level of realism and innovation to the next level.

Conventional CBT Method and its Limitations

As part of the final phase of the drug abusers' rehabilitation in prison, SPS conventionally administers psychology-based programmes which include the Cognitive Behavioural Therapy (CBT) method. These programmes aim to counsel inmates (via role-playing and talk therapy) to change for the better by working on existing mental models which may have led to their drug offences.

The sessions are more verbal in nature and the intent is to develop and build effective coping mechanisms in them prior to their release back to society. They essentially aim to reframe maladaptive thoughts, such as denial, minimizing and catastrophizing thought patterns, with healthier narratives (Dr. Mendonsa, Andrew. 2019). Specific techniques include identifying potential triggers and developing coping mechanisms to manage high-risk situations where the drug abusers are tempted to consume drugs. However, the aforementioned methods have the potential to increase in their efficacy in light of current technological advancements where it is now possible to render drug cues and triggers with greater realism during such therapy sessions.

SYSTEM OVERVIEW

As such, the Virtual Reality (VR) Cue Exposure Therapy (VRCET) system was conceptualized and designed by the Human Factors and Simulation Centre of Expertise (HFS CoE) from the Home Team Science and Technology Agency (HTX) in Singapore in collaboration with the Singapore Prison Service (SPS). HTX HFS CoE submitted a requirements approval document to the Internal Review Board for the research, development, and user trials of the VRCET system. The HTX senior management team subsequently granted approval to proceed with the research project and trial studies.

Heart rate and eye tracking sensors are integrated into the VR headset which enable the counsellors and psychologists to monitor and track the physiological state and well-being of the subjects objectively whilst they undergo the VR therapy sessions. The insights gathered from the heart rate and eye tracking data will enable SPS to determine the effectiveness or viability of cue exposure therapy on the subject. Ultimately, if the system is employed on a large scale, it could potentially enhance the efficacy of existing drug rehabilitation programs.

The system is highly portable as it essentially consists of a high-performance laptop connected via cables to a VR headset (HP Reverb G2 Omnicept Edition). The system can support the VR cue exposure therapy session for one drug abuser at any one time currently. The drug abuser undergoing the therapy session need to only wear the VR headset, whilst the psychologist would operate the laptop's graphical user interface as shown below in Figure 1.

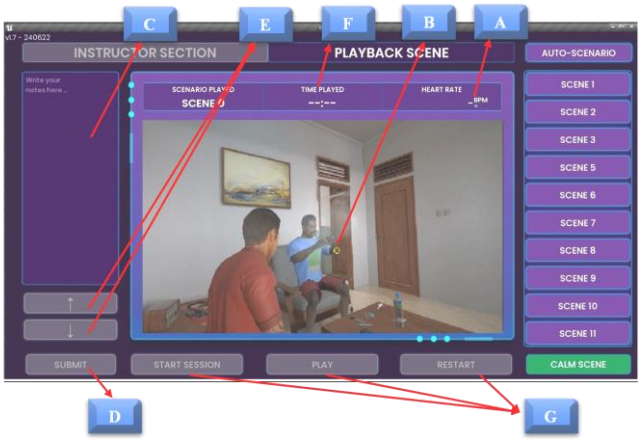

Figure 1. Key features of the graphical user interface

The key features of the graphical user interface (GUI) are as shown in Figure 1 below. They include heart rate (A) and eye tracking (B) displays, a free-text area for counsellor notes (C), "up" and "down" calibration buttons (E) for the adjustments of the subjects' VR viewpoint whilst donning the VR headset, duration of the VR session (F) and the "start/play/restart" buttons (G) for the psychologists' control of the VR sessions.

VR Storyboard highlights

The snapshot of the scenarios (1 to 10 followed by the "Calm Scene" at the end) are as illustrated below in Figure 2 (sequence as indicated by the blue arrows):

Figure 2. VR scenes and sequence of the scenario

The storyboard was designed in close consultation with the prison psychologists and counsellors. The intent of the design is essentially to increase the drug abuser's exposure to the drug cues incrementally as the drug abuser sits through the VR therapy session scenes, commencing from arriving at his friend's apartment to the introduction of a second friend, the drug preparation scene in front of him and finally the offer to take the drug.

The scenes intentionally incorporate social cues comprising visual and audio triggers of the subjects' friends coercing them to consume the drugs (scenes 1 to 11) as well as drug cues which include the drug paraphernalia and its preparation (scenes 6 to 9). The audio of the meth preparation like the clicking of the lighter and the bubbling of the crystal meth in the plastic bottle were intentionally accentuated to invoke past memories of the drug abuser. The 3D assets of these scenes are developed on Unreal Engine and their graphics quality is vivid, complete with the vocal recordings of the drug friends and the drug abuser from the actual drug inmates in prison. Parts of the storyboard scenes' scripts were also specially crafted to incorporate the local Singaporean dialect to increase and enrich the overall efficacy and realism of the VR therapy session.

PHASE 1 SYSTEM EVALUATION

In Phase 1 of the user trial, we evaluated and assessed the outcomes of the engineering aspects of the system and its effectiveness. The Phase 1 trial metrics include heart rate and eye tracking sensor accuracy, immersiveness of VR simulation and the overall system usability including the study of potential VR cybersickness effects on users.

Researchers from the HTX HFS and SPS teams collected user feedback after they interacted with the system in key areas such as VR simulator sickness, simulation interactivity and usability. By examining these areas, the study aimed to provide insights into the overall effectiveness and user experience of the VR system, ultimately informing the development of future system enhancements.

PHASE 1 METHODOLOGY

In Phase 1, a system trial was firstly conducted with SPS staff and counsellors in the SPS Headquarters (HQ) office premises (Figure 3). A total of twenty-seven (27) individuals participated in this trial with ages ranging from 24 to 49 years old. All of these participants received the same briefing, demonstration and surveys.

Prior to each trial session's commencement, each participant is briefed by the SPS researcher on the VR cue exposure therapy system's overall objectives, requirements and workflow. Each participant would first and foremost fill up a pre-screening health survey form which includes questions on frequency of use of VR technology in their daily lives, pre-existing health conditions like migraine headaches and stomach discomfort, alcohol consumption, insomnia and predisposition to motion sickness. Should any participant indicate a positive response to any of the health pre-screening questions, they would be excused from the trial session. Eligible participants were also briefed on the system's 11 scenarios prior to the commencement of the session. The efficacy and accuracy of the VR headset's heart rate sensor was compared against a medical grade pulse oximeter (Masimo MightySat® Medical Pulse Oximeter) attached to each participant's forefinger (Figure 4).

Figure 3. Phase 1 Participant in VR Trial Sessions

Figure 4. Medical grade oximeter

Heart rate readings from the oximeter were live streamed to the native oximeter smart phone app installed onto the researcher's mobile phone. Concurrently, the heart rate readings from the VR headset were displayed on the VR application GUI. At the end of each VR therapy trial session, an after-action review was conducted with the researcher where the participants' feedback was gathered, and they filled out the surveys described in the next section.

PHASE 1 DATA COLLECTION MATERIALS AND PROCESS

The following three surveys were administered immediately after the Phase 1 VR trial sessions:

1. **Simulation Training Safety – Simulator Sickness Questionnaire (SSQ):** The Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used in this study to measure simulator sickness. The SSQ is a self-reporting checklist comprising 16 symptoms commonly associated with simulator sickness. These symptoms are rated on a four-level scale, which are then converted into individual scores for "Nausea", "Oculomotor Discomfort", "Disorientation" and "Total Severity" to provide an overall determination on the degree of simulator sickness. An additional 4 questions were included to identify potential issues in physical ergonomics as well as audio or haptic discomfort arising from using the system (Stanney, Mourant & Kennedy 1998).

2. **Simulation Interactivity and Usability – Presence Questionnaire (PQ):** A Presence Questionnaire consisting of 32 items (Witmer, Jerome, & Singer, 2005) was employed to evaluate the participant's sense of presence in a VR system or virtual environment based on key considerations such as the degree of "Interaction", "Visual Fidelity", "Audio Fidelity", "Haptic Fidelity", "Interface Quality", "Adaptation" and "Immersion".

3. **Overall System Feedback –** This questionnaire seeks to gather additional feedback from the participants on the VR trial sessions, specifically on key areas which include VR simulation realism of the 3-D apartment assets and avatar friends, effectiveness of the "calm scene", interface quality and adaptation to the VR environment.

Data Normalization

After the survey data had been collected, we normalized the responses to eliminate any potential biases that may arise due to differences in interpretation or understanding of the questions being asked. It ensures that each participant's rating is on the same standardized scale, making it easier to compare the responses across different participants and different aspects being rated. The survey data sets are normalized such that each index in a data set is scaled to between a minimum and maximum value of "0" and "1" respectively.

PHASE 1 RESULTS

Simulation Training Safety - Simulator Sickness Questionnaire (SSQ)

In this survey, a normalised score of "0" constitutes a "no/nil symptoms severity" while "1" constitutes a severe or high symptoms severity rating. Participants gave an overall average "symptoms severity" response normalised score value of "0.03" across all questions. The most severe area of discomfort was found to be that of oculomotor (highest average "symptoms severity" score of "0.05") where in particular 6 (out of 27) participants indicated that they experienced slight eye strain during the VR sessions. The other two sickness categories "nausea" and "disorientation" also had a relatively low severity score of "0.02" each (Figure 5).

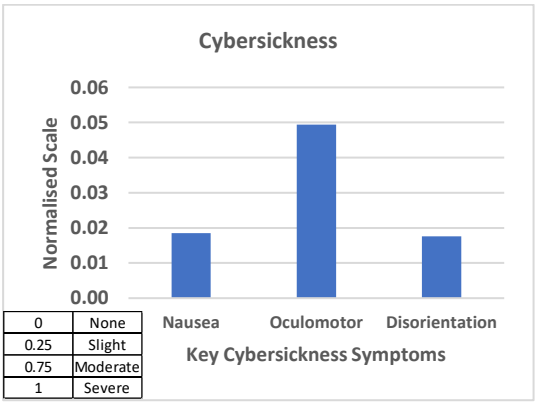

Figure 5. Simulator Sickness Questionnaire Results

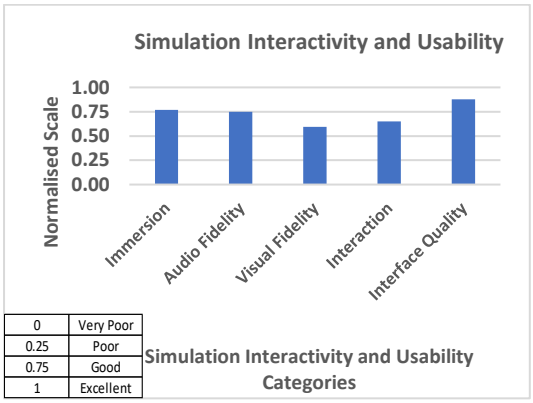

Figure 6. Presence Questionnaire

Regarding the aforementioned 6 participants who had indicated experiencing slight eye strain during the VR sessions, on further analysis, it was found that a majority of them had pre-existing ailments of migraine headaches and stomach discomfort.

Simulation Interactivity/Usability – Presence Questionnaire (PQ)

The system achieved a normalised mean score of "0.67" across all responses for simulation interactivity or usability. The lowest scored category is visual fidelity which had a score of "0.59" (Figure 6). This represents the accuracy with which the VR computer generated (CG) graphics reproduces the real-life environment from the participants' perspective. The survey questions include "How closely were you able to examine objects?" and "How well could you examine objects from multiple viewpoints?".

Considering the above, it is inferred that the key reason giving rise to this is mainly because in this Phase 1 trial, the participants were seated behind a desk and hence their movements were restricted. The highest scored category of "0.88" is interface quality which indicated the overall participants' feedback on the VR scenes'

interference/impact on their tasks/activities. Specifically, the participants felt that when donning the VR headset, the visual display quality of the VR scenes did not affect them in any way relating to their tasks or activities.

Overall System Feedback

The feedback and the comments from the participants were very positive. Most of the comments focused on how the system was able to increase the efficacy and realism of the VR cue exposure therapy sessions. Participants were generally quite optimistic that this new VR technology would have the potential to achieve its desired effect and objectives in helping drug abusers in their rehabilitation journey. The participants also provided suggestions for potential system improvements like providing more sensory cues including smell, touch and interactivity.

Efficacy of VR Headset Heart Rate Sensor

As part of the Phase 1 research, the accuracy and efficacy of the VR headset's heart rate sensor was analysed and studied in relation to the medical grade pulse oximeter (Masimo MightySat® Medical Pulse Oximeter) which was worn on the participants' forefinger throughout the VR sessions.

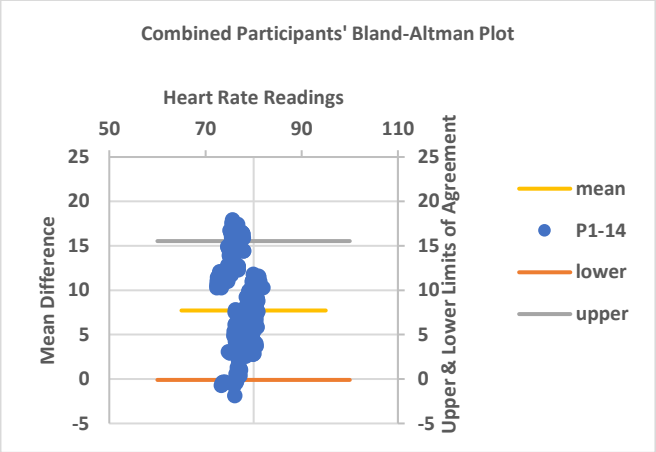

Figure 7. Combined Bland-Altman Plot for 14 Participants Efficacy of VR Headset Eye Tracking Sensor

We adopted the Bland–Altman plot technique which is effectively used to evaluate the agreement among two different instruments or two measurements techniques. If there is agreement, we would expect the values in the plot to cluster around the mean of the differences (called the bias), and within 2 standard deviations of the mean. Assuming the differences are normally distributed, this would result in a 95% prediction interval, called the limits of agreement (Zaiontz, Charles, 2017).

Datasets from the VR headset's heart rate sensor and pulse oximeter were collected and analysed for fourteen participants. Based on all the plots for the 14 participants (Figure 7), the VR headset heart rate and oximeter measurement readings are in agreement with each other: 95% of the difference in readings (from the mean difference) fall within the lower and upper limits of agreement of the plots. To validate the eye tracking sensor of the VR headset, the position of the eye tracking yellow circle indicator on the IOS display screen (Figure 1) across the VR scenario duration is validated against the participants' verbal communication to the researcher on what exactly they are looking at in the VR scene. The eye tracking sensor was validated to be accurate for 95% of the participants based on the above exercise.

PHASE 1 RESULTS DISCUSSION

The results from the SSQ indicate that the VR simulation has had minor or no adverse cybersickness effects on most participants in general. This is largely due to the fact that participants were seated throughout the VR therapy session. Mitigation measures were also taken such as calibrating the VR headset to each individual participant prior to each session and providing adequate briefing and familiarisation to the participants on the use of VR technology.

By virtue of the fact that the participants were seated behind a desk throughout the trial sessions, their ability to interact with the virtual 3-D assets in the VR environment was inhibited, thus giving rise to the relatively lower scoring in visual fidelity with respect to the rest of the scores. However, the overall scoring attained for the Presence Questionnaire was above average, owing largely to the high graphics quality and fidelity of the VR simulation. The VR headset's heart rate and eye tracking sensor data were also assessed and validated to be accurate and consistent in this Phase 1 of the trial.

Given the favorable Phase 1 trial outcome, the team commenced phase 2 trial with the drug abusers. With the above results and outcome of the Phase 1 trial data, it was established and concurred with the relevant stakeholders

from both HTX HFS and SPS that Phase 2 of the VR Cue Exposure Therapy POC project could duly proceed with the drug abusers.

PHASE 2 METHODOLOGY

The key objectives of Phase 2 of this trial are two-fold, mainly:

a) To evaluate the drug abusers' response to VR Cue Exposure Therapy (development of effective coping mechanisms to abstain from illegal drug use) and
b) Effectiveness of CBT with VR Cue Exposure Therapy.

A total of 20 drug abusers (or treatment group) in their final leg of their drug rehabilitation program were selected from the SPS Prison cluster to participate in this Phase 2 trial. As part of their rehabilitation program, the treatment group underwent conventional CBT with the counsellor prior to participation in the VR study.

Session #	VR Scenes	Social Cues	Drug Cues
1	1 to 2	Yes	No
2	1 to 4	Yes	No
3	1 to 6	Yes	Yes
4	1 to 8	Yes	Yes
5	1 to 11	Yes	Yes
6	1 to 11	Yes	Yes

Figure 8: Exposure of Virtual 3-D Drug Cues Across the VR Therapy Sessions

Informed consent was first obtained from all participants. Each trial subject then underwent a total of 6 VR sessions at 2-week intervals contingent on operational factors of their Prison cluster including their pre-scheduled daily regime and allocated tasks. User surveys were administered to the drug abusers at sessions #1, 3, 5 and 6, prior to the commencement of the session (pre-session) and after the session has concluded (post-session). The pre-session survey includes pre-screening health survey and the drug craving and avoidance surveys (for session #1 only). The post-session survey includes the drug craving and avoidance surveys (for sessions #3, 5 and 6 only) as well as cybersickness and simulation interactivity/usability surveys.

The VR cue exposure therapy sessions with the drug abusers were designed in such a way to gradually increase the VR scenes as the drug abuser progresses from one session to the next (Figure 8). This is to stagger the exposure and duration of the virtual 3-D drug and social cues to the drug abusers as they undergo the VR therapy sessions.

Separately, another group of 20 different subjects who fulfilled the same selection criteria (e.g., higher risk, completed CBT programs) was selected as the control group. This control group also completed the drug craving and avoidance surveys as elaborated in the next section below.

PHASE 2 DATA COLLECTION MATERIALS AND PROCESS

As in Phase 1, SSQ and PQ surveys were administered to the drug abusers after the respective VR sessions. In addition, the drug abusers' heart rate (HR) and eye gaze (EG) physiological data were automatically recorded, logged and stored onto the system laptop's storage drive. Key comments and feedback from the subjects were also gathered during the trial sessions on the usability of the system.

Two additional surveys entitled the "Visual Analogue Drug Scale for Craving (VASc)" (Culbertson, Christopher et al, 2010) and "Drug Avoidance Self-Efficacy Scale (DASES)" (Garth, Martin et al, 2010) were administered to the drug abusers prior to the commencement of the VR session (session #1) and after the VR sessions (sessions #3, 5 and 6). In this regard, we had labelled these sessions in which the drug craving surveys were administered as A, B, C and D, each corresponding to the VR sessions #1, 3, 5 and 6 respectively.

1. **Visual Analogue Drug Scale for Craving (VASc):** The Visual Analogue Drug Scale for Craving (VASc) is a 100-mm line on which participants have to rate their subjective experience of current craving for drugs, ranging from 'not at all' (0) to 'extremely' (100). Adapted from the VAS used by Culbertson et al (2010), the VAS form incorporated the following nine questions: four regarding urges to use drugs ("How much do you crave/want/desire drugs right now?", and "If you had access to drugs right now, how likely would you be to use it right away?"), two questions regarding mood ("How depressed/ anxious do you feel right now?") and three questions regarding physical state ("Do you feel any drug effect right now?", "How high are you right now?", and "How stimulated do you feel right now?"). Desire was specifically defined in subtext next to the question as "to want (a feeling)" and crave as "strong or intense need (an internal force)".
2. **Drug Avoidance Self-Efficacy Scale (DASES):** The Drug Avoidance Self-Efficacy Scale (DASES) is a 16-item scale adapted from the DASES used by Martin et al. (1995). It assesses drug-refusal self-efficacy,

where participants are presented with different situations involving drugs, and are to rate their perceived ability to avoid drug use in those situations on a 7-point scale ranging from 1 (Definitely cannot) to 7 (Definitely can).

PHASE 2 RESULTS AND ANALYSIS (VR SESSIONS #5 AND 6)

The treatment group subjects' mean heart rate and eye gaze (dwell time on each 3-D VR drug asset) datasets for each VR session were calculated across scenes 1 to 11. The datasets were then plotted across all 6 VR sessions to determine if any noticeable trends exist for the 20 subjects that underwent the trial studies.

Figures 11 to 13 below depict the 3 categories of data trends collated and plotted for the 20 subjects. The key focus of the analysis is on VR Sessions #5 and 6 where the drug and social cues were at their maximum exposure (subjects were exposed to all 11 VR scenes in both sessions), as indicated in the red boxes in the below plots. The similar trending patterns (upward or downward) in heart rate and eye gaze durations in sessions #5 and 6 are categorized as Categories A to C respectively.

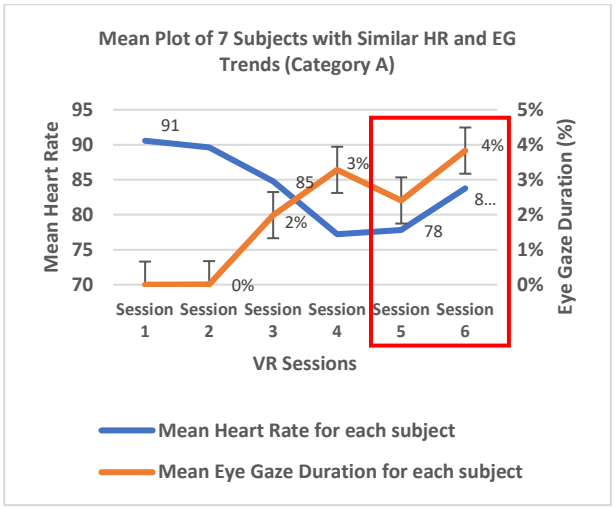

Figure 11. Category A Mean Plot of 7 Subjects with Similar HR and EG Datasets Trends

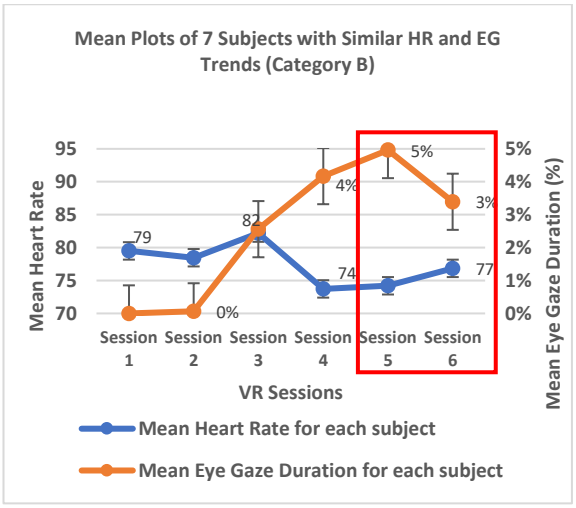

Figure 12. Category B Mean Plot of 9 Subjects with Similar HR and EG Datasets Trends

Subjects (35% or 7 out of 20 subjects of the trial cohort) under Category A (Figure 11) displayed an **increasing** heart rate and eye gaze duration trend (subjects #4,7,11,12,19,21,22) as they progressed through the VR sessions. Under Category B (Figure 12), drug abuser subjects showed **relatively stable** heart rate and **decreased** eye gaze duration (45% or 9 out of 20 subjects (subjects #5,8,9,10,14,15,16,18,20)).

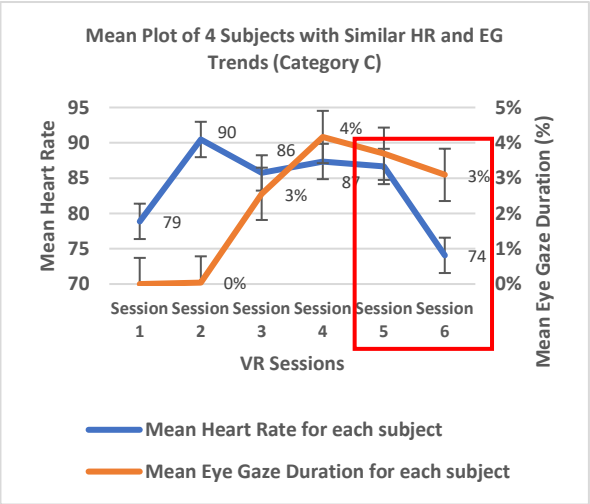

Figure 13. Category C Mean Plot of 4 Subjects with Similar HR and EG Datasets Trends

In Figure 13 on the left, Category C drug abuser subjects exhibited a **decreasing** heart rate and eye gaze duration (20% or 4 out of 20 subjects (subjects #2,3,6,17)).

Inferences from the Data Analysis Results

For Category A (Figure 11), subjects are shown to display symptoms of anxiety and being triggered by the drug cues in VR Sessions #5 and 6 as evidenced by their elevated mean heart rate and mean eye gaze duration data in these 2 sessions. This is further confirmed by the actual verbal responses by these subjects whereby they feedbacked to the counsellor that they felt triggered by the virtual 3-D drug and social cues in these latter VR scenes. In the final 2 VR sessions #5 and 6, the subjects were exposed to VR Scene #11 in which one of the drug friends intentionally reached out to the subjects with the prepared drug in his hand and both drug friends verbally coerced him to consume the drug.

Category B (Figure 12) subjects also exhibited an increased level of stress and anxiety (increased mean heart rate) due to the introduction of the drug preparation paraphernalia and the specific actions of the drug friend preparing the drugs and verbal cues of the drug friends coercing the subjects in the VR scenes from Sessions #5 to 6. However, unlike Category A, their mean eye gaze duration decreased from Sessions #5 to 6 and this can be attributed to the following 2 key factors:

a) Habituation of the subjects to the VR drug and social cues: over repeated exposures, the subjects became accustomed to the drug-related cues, reducing their initial heightened interest or craving response. This decrease in novelty can lead to reduced attention, reflected in shorter or less frequent eye gazes at the cues;
b) Cognitive effort: Initially, the subjects might focus more on the drug-related cues as they are highly relevant to their addiction. As they progress through therapy, their cognitive effort may shift towards managing their responses and utilizing coping mechanisms, reducing their gaze on the cues.

Under Category C (Figure 13), it can be inferred that certain subjects were not triggered by the VR drug cues in the latter VR Sessions #5 and 6 as evidenced by a decreasing trend in their mean eye gaze and heart rate. This could be deduced by the fact that these specific subjects were on syringe administered substances (e.g. heroin) prior to their incarceration. None of the VR scenes incorporated such cues or form of drug substances. Also drug abuser subjects under Category C could be inferred to have developed coping mechanisms to effectively reduce their desire in drug use. Verbal exchanges with the Prison counsellors confirmed this whereby these specific subjects shared that they thought of their family and loved ones when deciding the course of action to take when confronted by his friend's offer to consume the drugs in the last VR scene.

During the VR sessions 1 to 4, subjects in all three categories exhibited varied responses, indicated by fluctuating mean heart rates and eye gaze patterns. Heart rates generally decreased during the "Calm Scene" (Scene #4), which featured immersive visuals of a park with nature sounds. Periodic increases in heart rates were noted, often due to physical activity or exercise prior to the sessions, leading to higher baseline heart rates. Eye gaze duration gradually increased, corresponding with the incremental introduction of 3-D drug and social cues in the VR scenes from sessions 1 to 4.

Key Usability Comments from Subjects

Certain subjects provided positive feedback during the VR therapy sessions which include the high level of realism and immersion of the VR scenes and the calm scene which gave them a "sense of security". Other subjects provided constructive comments to improve the realism and engagement of the VR scenes such as incorporating olfactory trigger cues, VR scenes incorporating syringe-administered drugs like heroine and VR human avatars capable of interacting with the subjects.

Possible Limitations of Mean Heart Rate

The aforementioned approach, though robust in observing overall key trends in the drug abuser subjects' physiological responses to the VR drug and social cues, does present certain limitations or caveats. In actuality, there exists certain nuances whereby some of the subjects might have engaged in physical activities before participating in the VR Cue Exposure Therapy trial sessions with the counsellor and psychologist. This could have then elevated their baseline heart rate at the beginning of the VR sessions. Calculating the mean of the heart rates across may thus skew the outcome to a certain degree.

Actual Heart Rate and Eye Gaze Plot Across VR Sessions by VR Scene

As such, with the level of detail and depth of the subjects' individual heart rate and eye gaze datasets recorded and logged by the VR Cue Exposure Therapy system in all VR sessions, it would thus be feasible to study and analyse a specific drug abuser's heart rate and/or eye gaze reading at a selected time of a VR session and compare this set of readings across multiple VR sessions.

The aforementioned approach would preclude the series of heart rate data at the beginning of the VR session whereby the subject would still be in the state of recovery from his exercise session. Extracting the data at a mid-point time stamp of the VR session would thus be deemed sufficient to delve into the physiological state of any drug abuser to track and analyse the subjects' measured response to the 3-D cues across multiple VR sessions. This is illustrated in Figures 14 and 15 below.

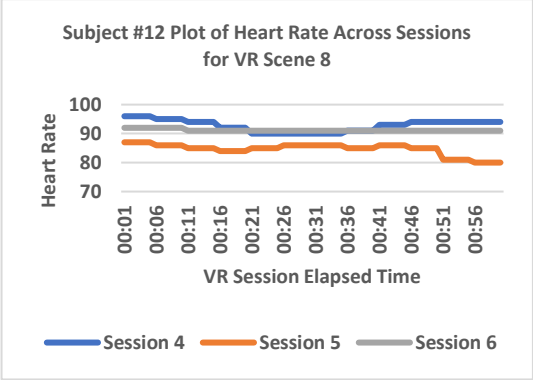

Figure 14. Subject #12 Plot of Heart Rate Data Across VR Sessions (VR Scene 8)

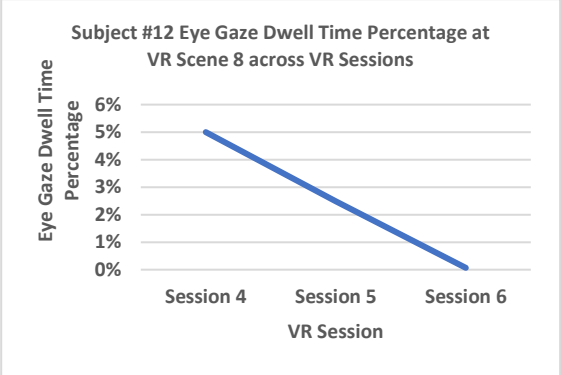

Figure 15. Subject #12 Plot of Eye Gaze Dwell Time Percentage Across VR Sessions (VR Scene 8)

PHASE 2 RESULTS (VASc and DASES drug craving and avoidance survey data)

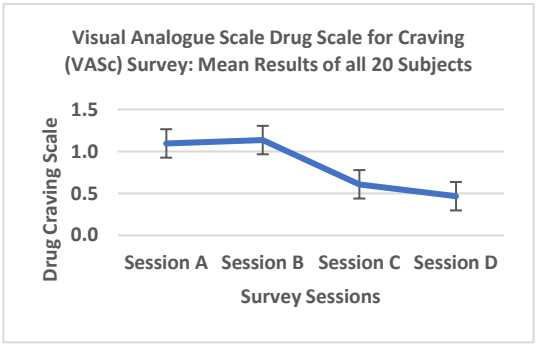

Figure 16. Results of VASc Survey

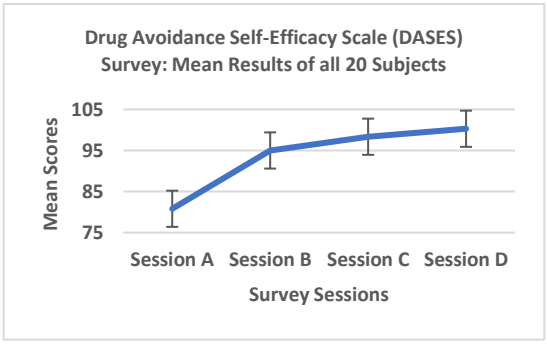

Figure 17. Results of DASES Survey

Data from the treatment group drug abusers' responses to the Visual Analogue Drug Scale for Craving (VASc) survey was collected and collated for further analysis. The mean survey scores of all 20 subjects for each session were then calculated and plotted in a line chart as shown in Figure 16 above. Based on the downward trending of the results from the survey sessions B to D (i.e. VR sessions #3, 5 and 6), it can be inferred that a majority of the subjects exhibited positive responses to the survey from VR sessions 3, 5 and 6. Their respective responses to the survey indicate that their feelings of drug craving have been diminished. The Drug Avoidance Self-Efficacy Scale (DASES) survey results (Figure 17) shows an increase in the mean response scores of the treatment group subjects from sessions A to D. Survey data from the control group showed similar trends of drug craving and avoidance as the treatment group.

Psychological Perspectives

Preliminary findings serve to highlight the criminology constructs of risk, needs, and responsivity towards rehabilitation of substance abusers, whereby it is not a one-size-fit-all solution. In this trial, although all participants had a long history of drug use (i.e., risk), different types of abusers could present with different needs (e.g., type of drug they use), which might have been limited by the current VR scenarios. In addition, preliminary physiological and subjective data demonstrate the responsivity construct, in that VR and cue exposure therapy might not be effective for all drug abusers. As such, to improve effectiveness, more personalization might be required for cue exposure intervention, which could be achieved through enhancing and enriching the interactivity, versatility and intelligence of the VR system and scenarios as described in the next section.

Next Steps: Future Work

This research proof-of-concept VR system certainly also paves the way for other potential therapy use cases in cue exposure including outrage of modesty and family violence offences. The physiological sensors employed in this study to measure the subjects' response to the VR therapy sessions are non-exhaustive; with the inclusion of EEG (electroencephalogram) and GSR (Galvanic Skin Response) sensors to the mix, further research and analysis could be performed on the subjects as an added dimension and depth to aid in the psychological wellness and rehabilitation of the aforementioned offenders. As a use-case example, specific VR scenarios could be designed and incorporated as pre- or post-intervention tools, as well as in training, to mitigate the risk of Post-Traumatic Stress Disorder (PTSD) among special operations forces. These scenarios would help personnel tune into their physical reactions to high-stress situations and control them for optimal operational performance. The VRCET system could also be potentially deployed to treat and address existing phobias they may have such as the fear of heights.

In the wider domain of homeland security training and education using immersive VR technology paired with physiological sensors, front-line police officers and firefighters could utilize this technology in their training to improve their effectiveness and situational awareness in life-threatening and stressful operations including terrorist incident response and threats.

With the recent pervasiveness of Generative-Artificial Intelligence (Gen-AI) technologies, the next phase of our research work would involve the creation of hyper-realistic and dynamic interactions with avatars in the VR scenarios. Incorporating facial expression and/or voice analysis, we aim to build and develop an AI engine capable of generating interactive virtual scenarios with avatars from the facial and/or behavioural inputs of the subjects. This would in essence create the hyper-realistic and interactive VR 3-D elements and meta-human characters that offer alternative branching scenarios to further immerse and expose the subjects in real-world trigger cues.

CONCLUSION

In conclusion, this pilot study demonstrates the potential efficacy of virtual reality cue exposure therapy as a novel intervention for ex-drug abusers as evidenced by experimental physiological data gathered from the Phase 2 trials. Broader and longitudinal studies are nonetheless needed to confirm these results and to optimize the therapeutic protocols for broader clinical application given the variations in the subjects' responses and nuances in their background and regimes. In light of emerging technologies such as gen-AI and more advanced graphics computing technologies, the Virtual Reality Cue Exposure Therapy System as discussed in this paper may, in the near future, be an impactful and innovative digital companion for counsellors and psychologists to assist drug abusers in developing effective coping strategies and mechanisms to overcome their drug cravings when they assimilate back into society. It may also be an effective intervention and training tool for other types of cognitive challenges such as PTSD and phobias. Further research, development and studies are thus warranted to validate its long-term efficacy in reducing recidivism amongst ex-drug abusers.

REFERENCES

Sayette, M., Shiffman, S., Tiffany, S., Niaura, R., Martin, C., & Schadel, W. (2000). The measurement of drug craving. Addiction, 95(S2(8)), 189‑210.

Conklin, C. A., & Tiffany, S. T. (2002). Applying extinction research and theory to cue exposure addiction treatments. Addiction, 97(2), 155‑167.

Mellentin, Angelina I. et al (2017). Cue exposure therapy for the treatment of alcohol use disorders: A meta-analytic review. Clinical Psychology Review 57 (2017) 195‑207.

Dr. Mendonsa, Andrew (2019). What Is Cognitive Behavioral Therapy? Expert Interview with Dr. Andrew Mendonsa. Sprout Health Group. https://www.sprouthealthgroup.com/treatments/what-is-cognitive-behavioral-therapy/.

Robert S., Kennedy et al (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness, The International Journal of Aviation Psychology, 3:3, 203-220, DOI: 10.1207/s15327108ijap0303_3

Stanney, Kay & Mourant, Ronald & Kennedy, Robert. (1998). Human Factors Issues in Virtual Environments: A Review of the Literature. Presence. 7. 327-351. 10.1162/105474698565767.

B. G. Witmer, C. J. Jerome and M. J. Singer (2005). "The Factor Structure of the Presence Questionnaire," in Presence, vol. 14, no. 3, pp. 298-312, doi: 10.1162/105474605323384654.

Zaiontz, Charles. (2017). Real Statistics Using Excel. https://real-statistics.com/reliability/interrater-reliability/bland-altman-analysis/bland-altman-plot/.

Culbertson, Christopher et al (2010). Methamphetamine craving induced in an online virtual reality environment. Pharmacology, Biochemistry and Behavior 96.

Martin, Garth W. et al (1995). The Drug Avoidance Self-Efficacy Scale. Journal of Substance Abuse, 7(2), 151-163.