Immersive and User-Adaptive Gamification in Cognitive Behavioural Therapy for Hypervigilance

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Abstract

This work proposes a novel combination of behavioural-tracking sensors and immersive virtual reality in a gamified proof-of-concept prototype, which demonstrates affective treatment concepts for hypervigilance symptoms. A number of limitations have been identified in current approaches, prompting more advanced techniques that efficiently target hypervigilance at an individual patient level. In response, we developed a virtual reality first-person shooter that responds to inertial user behaviour in a way that aims to combat detrimental symptoms, proposed as an exploratory investigation into innovative technology and its potential to maximise cognitive behavioural therapy outcomes for hypervigilance treatment. The prototype is evaluated through interactive user studies with 22 participants, gathering a large volume of qualitative data regarding participant experiences and opinions after use. Rigorous thematic analysis finds that participants can independently identify the cognitive behavioural therapy purpose of the intervention without prior knowledge of such intentions, and relate efficacious approaches from the literature to their own experiences. Despite prospective apprehension, themes also demonstrate widespread adherence and acceptance of such approaches to hypervigilance treatment, alongside perceived effectiveness both of experienced outcomes and future potential. These results support the validity of combining such technologies in the context of cognitive behavioural therapy interventions, such that the standard of future interventions may be improved.
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Index Terms—Virtual reality, gamification, mobile sensors,
cognitive behavioural therapy, exposure therapy

I. INTRODUCTION

HYPERVIGILANCE is a biological adjustment to severe
stress, inducing a heightened state of awareness and
perceptual sensitivity to potential threats in the environ-
ment [1], [2]. These symptoms of biased information processing
and confirmatory behaviour are common in various conditions
such as anxiety, PTSD and subjective loneliness [1]–[4], typically
leading to negative social behaviour and affect [1], [2], [5],
[6], social withdrawal [6], tension within relationships [2], [7],
and severe reductions in trust [2]. Given that hypervigilant
perceptions of threat are exaggerated in comparison to the
objective environment, worst-case scenarios are often the ones
anticipated, increasing attention towards manners of potential
rejection or negative reactions, therefore confirming negative
beliefs and causing an impulsive preference for solutions that
appear to provide the most immediate relief [1], [6], [8].

Methods of cognitive behavioural therapy (CBT), including
prolonged exposure therapy (ET), are found to be most effec-
tive in treating hypervigilance by encouraging behavioural
strategies such as deep breathing and meditation [2], [5].
However, a number of limitations have been identified in these
methods, including (1) the inefficiency of conversation-based
therapy, (2) the complexity of preparation regarding the diverse
and holistic nature of conditions, (3) the potential for detri-
mental or inaccurate evaluations, and (4) the ineffectiveness of
building upon a relaxed state in pursuit of successful treatment
[9]. Consequently, innovative technology advancements that
have proven valuable in related mental health interventions
may be applicable to hypervigilance while overcoming these
limitations.

Examining state-of-the-art mental health applications, user-
tracking sensors appear to be a beneficial solution to identify
affective behaviour and personalise treatment between diverse
individuals, as well as virtual reality (VR) in enhancing CBT
outcomes through an induced sense of immersion and in-
volvement. Given this widespread success, we investigate how
literature in this domain may be valuable in its application to
gamified hypervigilance treatment, incorporating technology
and concepts that are beneficial in related work. As a result,
an immersive VR first-person shooter (FPS) game with be-
avioural tracking qualities is designed as a novel contribution
towards advancing interventions for hypervigilance, proposed
as an introductory proof-of-concept that demonstrates how the
purposeful implementation of sensors and VR functionality,
particularly regarding treatment outcomes, may be applied
effectively in an engaging game format that directly addresses
the underlying cognitive biases of hypervigilance.

A. Research contributions

Our exploration into innovative technology research for
mental health finds that sensors, VR and gamification can
each be beneficial for enhancing CBT outcomes compared
to conversation-based CBT. While a handful of works utilise
sensors to gain insights into VR experiences, there are limited
contributions in combining these technologies – particularly
including gamification as well – built purposely to allevi-
ate mental health concerns. As such, our main contribution
demonstrates the integration of sensors, VR and gamification
as a self-contained system, where real-time biofeedback affects
the immersive gameplay experience, specifically designed to
adapt maladaptive user behaviour by reacting to their physical
responses. Another contribution is to address the gap in
which previous works do not develop technology to explicitly
improve upon traditional CBT limitations, which has been
taken into account during our design process.

Through practical user studies and interviews, we gather
qualitative data regarding user experiences and opinions of
such technology in a mental health context. Thematic analysis
highlights a prominent reference to recommended CBT con-
cepts from the literature, alongside the general acceptance of
such methods for treatment. These results support the potential treatment value of combining VR, sensors and gamification for mental health interventions, and demonstrates how each component can support CBT outcomes when integrated complementarily.

II. RELATED WORK

Previous work suggests that, while CBT has proven benefits, there is potential for technological interventions to enhance the delivery of these practices. As such, we seek to explore the role of gamified VR applications that track and respond to an individual’s hypervigilant behaviour in order to encourage beneficial cognitive bias modification, building upon techniques that are successful across innovations in mental health.

A. Sensors in mental health

‘Personal sensing’ is defined as the collection and analysis of data gathered from sensors embedded in the context of everyday life, aiming to identify human behaviours, thoughts, feelings and characteristics [10]–[13]. Devices such as smartphones, smart watches, fitness bands and external hardware tools all include a range of embedded sensors, in which contextual information about people and the environment can be interpreted through raw data, as well as by combining data from multiple sensors [10]–[13]. While the data itself may not reveal a person’s physical or mental state, personal sensing is undertaken as a means of recognising the behaviour emerging from its underlying physiological readings [10], [12], which in state-of-the-art models, may be analysed or predicted with machine learning [10], [11].

Various sensor types are utilised across mental health literature. Biomedical sensors such as heart rate monitors, eye trackers and perspiration sensors are primarily employed in the detection and management of anxiety conditions, allowing real-time measurements of biological changes that empirically correspond to anxiety attacks and related symptoms [14], [15]. Similarly, as acoustic features such as pauses or rate of speech are known to correlate with depression [16], [17], interventions utilising such analysis are typically performed through a smartphone’s in-built microphone [16]–[19], which have demonstrated accurate detection of depressive episodes in multiple languages to a standard comparable with live interviews [19]. Depression is also commonly tracked by processing GPS and WiFi data, allowing insights into location-based behaviours such as the amount of time spent in bed, with high accuracies both indoors and outdoors [18], [20], [21]. Bluetooth may be used in conjunction with these methods, defining the density of people within a small proximity of a user’s phone to approximately represent the number of people someone has been in the presence of, or alternatively, to determine if they are frequently alone [22], [23].

Detection of physical activity has accumulated frequent attention in previous works, typically employing various inertial sensors such as accelerometers, gyroscopes and magnetometers to determine a person or device’s motion, speed, direction and orientation [24]–[28]. Research has found strong correlations between physical activity levels and cognitive state, particularly for the diagnosis of anxiety and depression [18], [25], [26]. Inertial smartphone sensors have been successful in monitoring activity levels over time to identify and predict a range of distinct symptoms, with research predominantly targeting depressive episodes [26], [27], anxiety attacks [18], [27], mood changes [26] and stress levels [24], [28], as well as contributing factors such as sleep cycles and rest quality [25], [28]. By recognising patterns within this data, these interventions enable professional oversight and corrective feedback [18], [24].

The ability to capture user behaviour and understand cognitive processes pertaining to hypervigilance is vital in maximising the effectiveness of hypervigilance interventions. Incorporating sensors and data processing methods that are representative of such behaviours, the creation of personalised and responsive systems can address the inefficiency of current CBT approaches through automatic and unobtrusive analysis of patients, reducing the complexity of such analysis between individuals and the diverse and multidimensional nature of their conditions.

B. VR in mental health

More recent innovations in mental health are increasingly applying VR technology, in which users become immersed in a simulated 3D world that may be virtually explored or interacted with [29], [30]. By presenting the human senses with a virtual version of reality that can successfully synchronise its hardware and software components with implicit physiology, the resulting sensory information sent to the brain may cause users to perceive it as a real environment through the illusion of presence, particularly when virtual interactions parallel those performed physically in real time [31], [32].

By maximising components of presence – primarily attributing to the cognitive process of attention or mental models pertaining to a virtual space [31], [33] – VR has been associated with increased psychological arousal, allowing users to feel connected with the environment and, in the case of medical applications, improve their response to treatment as a result [33], [34]. VR has therefore been established as a means of achieving high ecological validity in its ability to induce naturalistic reactions, especially compared to those received in traditional laboratory environments [31]. For these reasons, mental health is widely regarded as one of the most promising applications of VR within a healthcare context [33], [35], [36]. It is predominantly applied to methods of ET in which patients are subjected to virtual stimuli representing their fears or anxieties, providing an opportunity to disconfirm negative expectations and practice positive behavioural responses [33], [37]. The dynamic nature of VR content is especially valuable in ET, in which therapists may control and manipulate the feared stimuli experienced by users with much more ease compared to traditional, ‘in vivo’ exposure methods [37].

Anxiety disorders, PTSD and similar mental health conditions are frequently targeted through these interventions, proven to better patients’ mental health to a larger extent than pharmaceutical alternatives while also promoting a safe environment with negligible side effects compared to that
of commonly administered medication [38]. Public speaking anxiety and social phobias in particular are greatly influenced by VR interventions, consistently shown to reduce symptoms among patients diagnosed with extreme anxiety [33], [35], [36]. In terms of temporal, environmental and monetary issues, VR interventions also remove the problematic task of audience recruitment, which has historically been a significant barrier to anxiety-related treatment [39]. For such reasons, researchers and medical professionals consider VR an ideal and practical tool for ET applications [35], [39] and applying theories of presence is a particularly important technique by which ET can successfully treat fears in a real-world context [35], [37].

With VR’s intrinsic psychological effects on CBT outcomes, its application has the potential to improve the delivery of such treatment. However, despite this control over a user’s external experience, insight into their internal experience remains uncertain due to a lack of understanding regarding physiological and emotional responses. As such, there is scope to integrate an affective understanding of users through sensors, not only to understand their underlying psychology, but also to use this data to influence the VR environment and encourage targeted behavioural change.

C. Combining VR, sensors and game design for mental health

The combination of VR and personal sensing is a newly accelerating field. Several unique VR devices have been created with increasing additions of embedded sensors, designed such that ease of use is prioritised by reducing complexity, intrusiveness, and the onerous setup of external sensors [40]. With these advancements, the gaming industry in particular has begun to utilise VR platforms alongside sensor data that influences game situations, typically personalising the experience based on the user’s reactions or psychological state [41], [42].

Previous research in game design for mental health has suggested that gamification can be beneficial in maximising treatment outcomes. Video games are often regarded as a beneficial tool to induce an enjoyable and self-rewarding sense of immersion when acting with total involvement [43]–[45], with the potential to fully engage users in treatment [46] through a readily accessible and stigma-free approach [47]. In particular, games are found to adhere to theories of intrinsic motivation and autonomy, alongside an easy and positive integration into everyday life [48].

Commercial games have demonstrated the ability to enhance users’ cognitive skills, such as information processing, attention control and cognitive flexibility [47], as well reducing levels of stress for people of all ages [49]. While improving upon psychological and cognitive behaviour in this way, it has been suggested that such approaches can be beneficial for managing detrimental symptoms and coping strategies through behavioural practice [47]. For example, therapeutic games have established a clinically measurable decrease in anxiety symptoms by using gamified intervention strategies such as deep breathing exercises [49], [50], while exergames have been beneficial in alleviating both stress and anxiety [50] to a level comparable with traditional exercise [51]. In general, gamification is most powerful in its ability to target behavioural outcomes rather than impact cognition [48], where games utilising biofeedback have better CBT outcomes than conventional games [52]–[54].

As such, combining the self-autonomy, immersiveness and behavioural influence of games may augment the therapeutic benefits of VR and sensors. One of the most prominent examples this combination is Nevermind1, described as a “biofeedback-enhanced adventure thriller game” that assesses and responds to levels of stress or fear. Nevermind alters various aspects of gameplay such as difficulty with the intention of challenging players to overcome their fears by improving their emotion regulation skills. Although originally developed for PC and console platforms, its subsequent upgrades support both the HTC Vive and Oculus Rift.

A large number of off-the-shelf sensors are compatible with its emotional state detection algorithms, such as heart rate monitors, eye trackers and basic webcams that employ facial recognition and emotion detection. While each sensor provides an accurate experience in itself, combining these sensors is said to provide an extremely responsive experience that reacts to player behaviour in the most appropriate way. Nevermind has been utilised in various scientific studies, exploring its ability to induce serenity [55] or stress [56], improve interoceptive awareness [57], encourage engagement and enhance usability from a design perspective [57]–[59], along with many more applications. Typically its performance and anticipated future potential is high, and such innovative methods have been considered an entertaining and rewarding method of human analysis through successful results in the research community [56]–[59].

Despite a general lack of gamification, specialised mental health applications provide comparable findings. Real-time insights into VR experiences have been proven beneficial for biofeedback, the assessment of conditions or patient progress, and methods of treatment personalisation [40], [60], [61]. Combining VR therapy alongside integrated sensors’ natural collection of personal sensing data often demonstrates success in mental health treatment, particularly for conditions related to anxiety, phobias and PTSD symptoms [9], [60]. For instance, headphones designed by sensor-embedded VR specialists Amelia2 are applied in various mental health contexts, using the system’s pre-prepared environments such as ones designed for agoraphobia [60]. Studies utilising these devices validate their ability to clinically improve patients’ conditions, with reductions in both subjective units of anxiety and galvanic skin response using electrodermal sensors [9], [60].

As such, we establish that VR, sensors and gamification each present diverse capabilities to improve upon users’ mental health when effectively designed for this purpose. While previous work has – to differing extents – demonstrated the anticipated impact of these elements when combined, its real-world applications have been limited despite the established potential in maximising CBT outcomes. In this sense, such

1https://nevermindgame.com
2https://ameliavirtualcare.com/
approaches are rarely utilised in mental health interventions, both throughout research and in clinical environments.

III. Intervention Design

Given the established potential of VR, sensors and gamification for mental health assistance, we design a prototype intervention that aims to incorporate the technology components and CBT concepts that are successful in related work. Before intending to solve hypervigilance symptoms, this proof-of-concept exploration first demonstrates the innovative combination of these technologies in practice, and the capacity to improve upon existing treatment.

A. Prototype description

As methods of CBT and ET have been identified as those most effective in treating hypervigilance – particularly addressing underlying maladaptive cognition and encouraging positive behavioural strategies as a result [2], [5] – the proposed intervention design aims to incorporate these concepts in order to promote cognitive and psychological change. Specifically, deep breathing and meditation techniques are most commonly recommended such that patients are able to practise mindfulness and recover from anxiety or stress caused by hypervigilant behaviours [2], [5], embedding strategies that are practical in everyday life [2]. Over time, this behavioural adjustment aims to reduce and potentially eliminate hypervigilant symptoms, and overcome the anxiety it causes.

While keeping the required skill level low to ensure that physical or cognitive skills do not impact game proficiency [62] or add unnecessary task demands [48], we implemented a prototype VR first-person shooter (FPS) game in which enemies are consistently spawned in random locations surrounding the user’s position. While enemies fire projectiles towards the user, the user may also shoot these enemies by aiming with a dedicated VR controller, additionally having the ability to dodge incoming attacks through physical movement. To demonstrate ET approaches, the continuous and fast-paced spawning of enemies represents hypervigilance at a primitive level, denoting threats that are anticipated in a typical environment. This surface-level implementation of hypervigilant characteristics aims to approximate such behaviours for demonstrative purposes, rather than pursuing clinical accuracy.

Incorporating mechanics of deep breathing and meditation, a slowed user state – arising with a change in sensor-detected movement behaviours – is measured wirelessly through an external smartphone’s gyroscope data, which subsequently triggers easier gameplay by reducing enemy spawn and shooting rates, as well as shooting speed. From a CBT perspective, the intervention intends to encourage and reward such responses within a simulated hypervigilance environment by demonstrating beneficial outcomes during this meditative state, aiming to embed an inherent change in behaviour whenever users become overwhelmed.

B. Design justifications

As in ET principles, stimulating high levels of alertness within an immersive VR environment creates a more applicable scenario for hypervigilance adaptation, rather than the unproductive context of relaxed environments [9]. According to theories of presence, overtaking the senses of sight and sound improves spatial presence by completely immersing users within the virtual environment, as well as involvement by suppressing external distractions and allowing users to engage fully with interactive virtual stimulus [32], [33]. Perceived ‘realness’ is also affected such that virtual movements, both through the headset and VR controller, correspond with those performed physically in real time in order to coincide with users’ real-life expectations [31]–[33].

Along with its first-person nature, these factors contribute towards a sense of ownership and self-sufficient control [43], [63], and by maximising presence in this way, previous research has shown that users are more believing and involved in their treatment than in traditional lab environments [33]. The ability to measure and adapt to affective user reactions also intends to change maladaptive cognition and behaviour through CBT, in which treatment stimulus can be personalised according to individuals’ physiology and interactions in response to the simulated environment.

Fig. 1. Prototype screenshot showing (a) an enemy, the VR controller cursor, and near-full health, and (b) a successful enemy hit, lower health and a higher ‘enemies hit’ score.
As previously highlighted, there are a number of shortcomings in current CBT approaches [9], and so the employed concepts attempt to respond to these limitations and improve the standard of hypervigilance treatment. Firstly, the use of automated and self-contained technology interventions utilising VR and sensors reduces the need for time-consuming conversational therapy, highlighting innovative alternatives that have a comparable ability to influence intrinsic cognitive behaviour in a targeted manner. The use of behavioural-tracking sensors additionally accounts for the multidimensionality and complexity within and between individuals, which not only automates the process of intervention personalisation and therefore minimises the complexity of clinicians’ preparation, but also provides objective, absolute values that represent patient behaviour, limiting the chance of biased or inaccurate evaluations.

C. Implementation of behavioural analysis

To incorporate meaningful representations of contrasting hypervigilant and meditative behaviours, a preliminary user study was performed upon the development of game functionality to investigate which sensors and processing techniques are most appropriate in algorithmically defining these behaviours.

Focusing on low-cost smartphone sensors, metrics for inertial movement through accelerometer, gyroscope and gravity sensors were each logged to decide upon the best approach to measure a user’s movement. Overall, these decisions determine how this data should be implemented in order to influence the virtual FPS environment, changing the game’s responsive state through real-time adjustments in its speed and difficulty. This study was approved by the Research Ethics Committee at Swansea University.

1) Procedure: Six participants were recruited locally from a PhD office in which selection criteria was minimal, only requiring an adequate level of sight, hearing and mobility, along with the dexterous use of one hand for controller interactions. Each participant took part individually, lasting around 10 minutes in each case.

During the study, an informal interactive session to demonstrate deep breathing and meditative behaviours was first provided for participants to ensure they could adequately perform the behaviours that aim to be identified through sensor analysis. After setting up the VR and smartphone devices – correctly fastening the headset and placing a preconfigured smartphone within any available clothing pocket – participants were asked to play a full round of the game one or more times depending on their elapsed gameplay time. While observing the reactions of individuals during gameplay, each participant was encouraged to undertake deep breathing and meditation exercises when becoming visibly vigorous or overwhelmed, in which timestamps denoting the start and end times of these changed behavioural states were noted. Alongside active gameplay, real-time sensor data was streamed wirelessly from the smartphone, stored and graphed for visual analysis. By correlating the observed timestamps of contrasting changes in behavioural state, graphed sensor data was labelled according to these states. As such, each participant produced three labelled graphs of sensor data denoting their movement throughout gameplay, presenting the smartphone’s in-built accelerometer, gyroscope and gravity sensors over the duration of the study.

2) Results and integration: The resulting graphs show the streamed data for each sensor in timeseries format. In each graph, the X-axis denotes consistent units of time in which packets of sensor data were transmitted, while the Y-axis relates to the absolute values of these sensor readings in three-dimensional space. Highlighting the areas corresponding to observed meditative timestamps allows these behaviours to be differentiated from typical gameplay states through simple visual evaluation, which shows clear differences even while the smartphone device is stored in the user’s pocket.

Visually comparing graphical trends across each type of sensor, the gyroscope sensor appears to provide a more distinct and consistent reading of meditative behaviours, given the high contrast between default and slowed gameplay states. All three gyroscope axes are within the range of -0.15 to 0.3 when categorised as meditative, which holds consistently for
all participants in the study. As a result, the gyroscope sensor was thought to provide the most accurate and appropriate data for simple identification of separate behavioural states, where a consistent range of -0.15 to 0.3 may be used to distinguish the deliberate application of deep breathing and meditative strategies from high-movement representations of hypervigilance.

As such, the intervention’s implementation included this threshold as a comparison with incoming sensor data, triggering adjustments within the virtual environment – either slowing the game or increasing its difficulty – to accommodate the user’s behavioural response. Given the small sample size and exploratory stage of this work, this simple processing approach is deemed adequate in approximating hypervigilant and contrasting meditative user states.

IV. USER STUDY

As the discussed technology interventions are typically successful in various mental health domains, the integration of these concepts within a hypervigilance context is hypothesised to produce comparably successful results.

To evaluate the developed prototype in its purposeful combination of personal sensing, VR technology and FPS functionality in accordance with literature concepts of effective CBT, a practical user study considers the functional potential and value of such ideas in application to mental health interventions, specifically targeting symptoms of hypervigilance. As no such interventions exist within hypervigilance treatment, evaluating this prototype aims to provide the foundations upon which hypervigilance and general mental health interventions may be improved with further development.

Gathering qualitative data regarding users’ experiences, opinions and learnings throughout their use of the intervention is a main focus of this introductory study, supporting an understanding of the extent to which such intervention strategies are suitable in the application of hypervigilance treatment. Again, this study was approved by the Research Ethics Committee at Swansea University.

A. Procedure

With the intention of analysing human-centred insights into user interpretations, the study procedure involves a one-to-one session with each participant in a quiet designated room for approximately 30 minutes in total. The overall process includes (1) a small demographic questionnaire to gather preliminary data, (2) practical use of the intervention while observing physical behaviours, and (3), a detailed interview covering pre-determined topic areas in a semi-structured manner, aiming to formulate an understanding of such interventions’ pertinence.

With no medical-specific target audience at this stage, participants were recruited locally with a selection process similar to that of the previous sensor-based study during development, including adequate levels of sight, hearing, mobility and the dexterous use of one hand for VR controller interactions. As such, using these criteria intends to gather as many participants as possible by enforcing no further restrictions, however those who took part in the initial sensor-based study were excluded given their prior experience with the prototype intervention.

Within the first phase, participants completed a pre-study questionnaire to allow the assessment of demographic data such as age and gender, along with important preliminary information including familiarity with FPS games and VR technology.

Participants were then instructed to use the prototype intervention, equipping the VR headset and smartphone device with minimal guidance regarding the system’s purpose or functionality. For each participant, multiple playthroughs of the game were completed to allow for better familiarity with the controls and exploration of the inertial sensor data’s influence, where behaviours and changes over time were observed and textually recorded. Given the self-contained interaction process of this gamified intervention, participants were able to use it with freedom and independence, without the need for external instructions and resources.

As VR obscures vision of the physical environment, this phase was performed in an open space permitting unrestricted movement, ensuring no obstructions were exposed. As such, the study took place in a safe location that minimised the risk of injury or interference. All participants were additionally made aware of potential motion sickness caused by VR, particularly when the headset device is not fitted correctly to the user [64]. As a result, extra caution was ensured when setting up the device, and participants were instructed to stop the study at any point in which such sickness may occur, as well as in the case of any other forms of physical or emotional detriment. Through these mitigations, no participants experienced physical interferences or motion sickness during the study, and expressed no manner of further harm.

On completion, participants were to report their experience and findings through a semi-structured interview, covering the overarching topics of perceived purpose, acceptance and suitability, along with experienced or recognised effectiveness of such methods in practice. After reviewing initial thoughts about the intervention, its intended purpose and underlying concepts were conversationally discussed to gather more tar-
geted responses regarding practicality and the meaningfulness of implementation. In this sense, the interview aims to evaluate whether the intended, expected or desired behaviours are caused as a result of interacting with the intervention, such that no declarations of treatment efficacy or expected outcomes were proposed or intended. Additionally, no data about users or their inertial state is stored by the application itself, only processed in real-time, further containing no use of personal, identifiable or sensitive information. As a result, the initial questionnaire collecting demographic data was the sole inclusion of personal information within this study procedure, namely including participants’ age range and gender as well as technology-based experience, however this data is entirely anonymised and possesses no identifiable indications.

Participant responses are noted manually throughout this third phase, and utilising textual comments concerning both the interview and observation stages, thematic analysis [65] is applied to investigate prevalent conclusions such that categories of results may be compared across the population.

B. Demographics and preliminary data

In total, 22 participants volunteered to participate in the study, recruited locally via verbal advertising throughout the university, subsequently distributing to further populations through word-of-mouth. As such, the majority of participants (17) were students between the ages of 18 and 27, with the remaining participants (5) being non-students ranging from 20 to 56 years of age. Of these participants, 13 were female and 9 were male.

As the study simply intends to demonstrate such intervention strategies in practice, no hypervigilant participants were recruited in order to minimise the possibility of harmful reactions or experiences. At this stage, a baseline evaluation of the concepts and techniques implemented is first necessary before analysing clinical impact. Through Likert scale questions regarding VR and gaming experience, an overview of the participant population shows that only two classified themselves as very experienced with VR, owning their own personal VR devices. While four stated to have used VR before, the remaining participants consider themselves to have little or no experience. However, a much larger majority have experience with FPS games, five regarding themselves to be highly experienced and only three having no experience, the rest having an adequate level experience. Despite the predominance of little VR experience and standard FPS experience, a widespread range of abilities are provided, facilitating usability testing across a variety of users.

Given the exclusion of those who had previous involvement with the prototype design, all participants additionally had no knowledge about the intervention and its potential or intended interactions, or further, regarding the context in which it may be used.

V. RESULTS

Thematic analysis was conducted on both interview responses and observed behaviours during intervention use, following the thematic steps suggested by Braun and Clark [65]. After studying the data, the text was both inductively and deductively coded from participant opinions and experiences, through which overarching themes denoting CBT concepts, acceptance and apprehension were categorised. By reviewing these themes and the patterns throughout the data, each theme was finalised according to its evaluation of the prototype, summarised in Table I along with their frequencies.

A. CBT concepts

A major theme throughout the study involves CBT concepts that align with those discussed in relevant literature. Participants commonly referred to the approaches and goals of CBT indirectly, and implied an importance of such concepts in application to mental health interventions. Within this area, various subthemes emerged, including an induced alertness resembling ET, VR immersion and presence, as well as perceived behavioural change.

1) Alertness: Responses from every participant included words like ‘fast’, ‘alert’ and ‘aware’ in reference to the virtual FPS environment, in which the game was associated with a need for high levels of cognitive awareness. Four in particular related this concept to measures of CBT, suggesting that such an environment helps to overcome and deal with related over-awareness after becoming familiar with the experience. Approximating hypervigilance to high levels of alertness in this context, a fundamental value of ET – exposing participants to stimuli in which they can practice controlling their symptoms – may be demonstrated within the developed prototype.

2) Immersion: Increased focus and perceived realism were both prevalent in participant experiences when using the prototype, shown to be effective for engagement and believability within virtual ET. While 18 implicitly implied that the headset removed external distractions through casual remarks such as “I was definitely more focused on the game when it’s the only thing I can see”, seven specifically used the words ‘immersion’ or ‘immersive’ when describing the VR experience. Spatial presence was also included in 19 responses, in which participants ‘forgot’ about their physical surroundings and, in an instinctive sense, “sometimes thought it was real”. This was consistent with observations during prototype use, where participants would occasionally shout or flinch upon virtual projectiles’ impact.

3) Behavioural change: During the observation phase of the study, a meditative state was often utilised to slow gameplay alongside increased levels of perceived difficulty.

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<thead>
<tr>
<th>Theme</th>
<th>Subthème</th>
<th>Frequency</th>
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<td>Immersion</td>
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typically used as an opportunity to pause and take a noticeable deep breath. All participants intuitively understood this functionality, stating that slowing physical movement “slowed everything down” during gameplay and “made it easier for a while”.

Without prior knowledge of the prototype’s purpose, 13 explicitly recognised a sense of recovery from stimulated alertness, such that it “lets you breathe and calm down when [the game] is getting hectic”. Four participants self-identified a personal experience of learnt behavioural change in which they felt influenced to slow down when becoming overwhelmed, therefore prompting an active change in behaviour as a result of using the prototype.

“It’s almost like it teaches you to try and be calm when you’re too worked up.”

Upon direct questioning on this subject, an additional 12 participants stated that they may have become more prone to deep breathing and meditative approaches to address simulated alertness, particularly over sustained use. Correlating with observation – where participants actively utilised the ability to slow game speeds to take visible deep breaths – participants often became more efficient in managing heightened alertness over time, subsequently improving game progression.

B. Acceptance

Acceptance of the employed technology was another key theme in which participants were generally supportive of the prototype’s concepts across various aspects. Throughout the population, the factors most commonly contributing towards this acceptance, each discovered as a significant subtheme within this data, included the accuracy of sensors in distinguishing ‘hypervigilant’ and ‘meditative’ user states, trust towards the type of sensors and data being used, a sense of enjoyment arising from gamified functionality, and regards of high future potential.

1) Sensor accuracy: Participants often endorsed the prototype’s accuracy of inertial behaviour identification. Eighteen independently acknowledged these sensors using words such as ‘effective’, ‘consistent’ and ‘precise’ such that only deliberate changes in physical state influenced the environment as intended. These 18 participants further found importance in this data’s affective contribution towards the prototype’s CBT purpose, expressing that the accuracy of sensors allows the VR environment to be updated appropriately.

2) Data: Another prominent feature of acceptance included the implementation of minimal, relevant and anonymous data. While 20 participants stated that the minimal use of data positively influenced their acceptance of the prototype, 11 of these participants were further influenced by the exclusive relevance of this data, expressing value in that this method “only uses data that’s relevant and nothing else”. Every participant additionally noted that the data’s anonymous and non-personal qualities were a main factor considered to improve this acceptance, given that the risk of harm through data leaks or misuse is minimised.

“Just seeing numbers about my movement doesn’t really mean anything [personal or identifiable].”

3) Enjoyment: Responses from every participant conveyed a sense of enjoyment when using the prototype. Gamified FPS functionality in particular was commonly deemed ‘fun’ and ‘entertaining’, and despite the established requirement for high cognitive alertness, all participants expressed that the experience was not stressful in the sense of causing panic or anxiety, only in that the constant stimulation increased their attention towards virtual activities. Comments regarding enjoyment were most significant within themes of acceptance, influencing the entire population’s approval and adherence.

4) Future potential: The future potential of this technology when developed at a higher fidelity is a commonly recurring subtheme regarding acceptance. In particular, utilising such an intervention over prolonged and consistent applications was comprehensively thought to be a method by which technology can effectively embed positive behavioural strategies into real-life scenarios. Despite our introductory implementation, 19 participants believed that the most novel and useful feature within the prototype’s design was to “measure [behaviour] in response to the game” and subsequently “use people’s reactions to update what they’re experiencing”. Participants regarded advanced algorithms that follow these concepts to be a promising and efficient method of treatment. Further, 12 participants expressed value in the potential to analyse captured data to find patterns and trends, which therefore “lets doctors understand their patients more objectively”.

C. Apprehension

Using FPS functionality as a representation of hypervigilance derived a smaller but crucial theme of apprehension towards deployment within a mental health context, specifically regarding the deliberate attempt to impose a hypervigilant state upon someone. Four participants expressed initial concerns such as “maybe it’s not ethical to put someone in that state”, especially for users that may be vulnerable. However, these participants did agree that their own personal experience was enjoyable and that, as the prototype design stands now, it is unlikely to cause psychological harm. Further comments suggested that, by implementing such strategies in a recreational gamified form, potential detriment may be minimised.

VI. DISCUSSION

Overall, results suggest that the prototype adheres to methods of successful CBT as defined in existing research, and while some ethical concerns arose, such approaches were widely accepted across the population.

Relating to effective approaches of ET, both alertness and immersion were commonly identified by participants. Inducing an increased alertness – approximating hypervigilance in the case of this prototype – conforms to the key principles of ET, in which subjecting users to virtual stimuli representing their anxieties or detrimental behaviours provides an opportunity to disconfirm negative expectations and overcome these symptoms by adopting positive behavioural strategies [33], [37]. In this sense, building upon a relaxed state is ineffective in addressing maladaptive cognition and behaviour [9], therefore demonstrating how the prototype is beneficial in inducing
a ‘hypervigilant’ state that is necessary for psychological modification.

Similarly, the immersion participants experienced through VR evidences theories of presence. Correlating with existing research, results suggest that VR intrinsically removes external distractions and instead encourages better attention and engagement with virtual CBT [31]–[33]. Previous work has considered this engagement to be the most influential component of presence given that greater attention towards fear-related stimuli improves the effectiveness of ET treatment [33]. While this was the most frequently recognised component of presence, participants also noted that immersion made the experience more real and believable.\textsuperscript{8} As defined in theories of presence, connecting physical actions and expectations with virtual experiences increases perceived realness [31], [33], which is an important contributor towards ET effectiveness given that fully embracing and believing in virtual stimuli is essential for psychological fear structure activation [33], [66]. Without such activation, ET may not be as effective [66].

Combining these qualities recommended in enhancing CBT outcomes, the prototype was able to elicit some form of behavioural change. Participants expressed better management of stimulated awareness over time by utilising the meditative behaviours that were implicitly encouraged, therefore adopting a change in maladaptive behaviour as a result of immersive and user-adaptive approaches. Some independently recognised behavioural benefits of this adaptation, relating it to CBT goals and motivations.

All participants expressed that using the prototype was fun and entertaining, and favoured the idea of playing games as a way to improve upon their cognition and behaviour. This sense of enjoyment was the most significant factor in positively influencing the acceptance of such technology, correlating with previous research that finds gamification to encourage active participation through its enjoyable and self-rewarding nature [43]–[46].

The particular application of sensors also influenced acceptance in a mental health context, regarding accuracy, use of data and its future potential. While participants found value in the consistency of behavioural recognition – stating that only intentional movements resulted in a change of game state – the use of data that was minimal, anonymous and exclusively relevant more directly affected trust. Consequently, these characteristics adhere to common values of trust and acceptance regarding data and its usage.

Given the low fidelity of this prototype, participants additionally recognised the potential of such technology in future iterations, in which affectively combining VR, sensors and gamification may be a technique by which interventions can be more enjoyable and productive. While participants found the current sensor data to be satisfactory in differentiating user states, many believed that more advanced algorithms could precisely model a user’s psychological state and behavioural trends, and therefore personalise treatment stimulus in VR as well. Previous works prove that inertial smartphone sensors are capable of capturing human behaviours that correlate with mental health conditions [24]–[28], which demonstrates future potential to use this data more effectively. This analysis may be further improved by aggregating more sensing modalities, as suggested throughout personal sensing literature [67], [68].

Experts argue that personalisation, made possible through these methods, is essential in maximising CBT outcomes [10], [67] and allows the application of tailored approaches over prolonged and consistent periods of time [3], [9], [33]. All participants identified this promising potential, thought to be one of the main advantages of using this combination of technology in order to gather user information through virtual experiences, personalise treatment stimulus, and embed positive behavioural strategies that can be used in day-to-day life.

As a result, the enjoyable nature of games, the accurate and trustworthy use of data, and the potential to enhance CBT by combining VR, sensors and gamification were large contributors towards the acceptance of such technology in mental health contexts. However for a small number of participants, ethical concerns contributed negatively towards acceptance. Deliberately inducing a hypervigilant state upon someone created uncertainty in the way that users might react, particularly those who are vulnerable to hypervigilant behaviours. Despite its potentially negative connotations, ET research emphasises the necessity of evoking such responses in order to fully embrace and address symptom-related stimuli as discussed [33], [66]. These concepts were additionally recognised by these participants, ultimately outweighing previous comments of apprehension. The enjoyable and abstracted nature of the gamified experience greatly contributed to these beliefs, such that harm may be less likely to occur.

Overall, the majority of guidance has been met regarding successful CBT approaches – such as augmenting presence and realness – and has demonstrated the potential to personalise treatment experiences that are tailored to user responses. This potential, among other factors such as enjoyability, accuracy of behavioural recognition and the trustworthy use of data, conforms to the values and expectations of acceptance identified collectively by participants. While some initial concerns arose regarding the ethical implications of inducing a hypervigilant state upon users, participants also understood the requirements of ET, additionally stating that gamifying the experience may decrease the potential for harmful reactions. As a result, such technology could be accepted in the context of mental health interventions, demonstrated by the prototype’s introductory implementation of these concepts.

\textbf{VII. Conclusion}

This research aimed to explore the novel combination of personal sensing, VR and gamification – which have each proven successful in addressing general mental health conditions – such that CBT outcomes can be maximised by incorporating the beneficial characteristics of each technology component. In application to hypervigilance, the prototype was often compared to efficacious concepts discussed throughout relevant literature, and was widely accepted as a form of recreational therapy despite some initial apprehension.

This work hopes to justify further developments into these methods that have not yet been combined for this purpose,
providing a foundation upon which hypervigilance treatment, as well as general mental health treatment, may be improved to overcome the limitations faced in traditional CBT.

A. Limitations

Some limitations have affected the way this research was conducted and evaluated. As a result of both ethical and recruitment concerns, hypervigilant users were not included in the study. While this means that the prototype has not been evaluated by its target audience, the preliminary study conducted first aims to explore the suitability of VR, sensors and gamification when combined for CBT purposes, providing a foundation for higher fidelity works to build upon rather than aiming to achieve treatment success at this stage. In this sense, an association with effective CBT concepts has been established, as well as a general acceptance of such methods, providing justification to commit to clinical studies.

Similarly, evaluating the prototype solely using subjective participant experiences was also deemed adequate for the introductory nature of this research, giving insight into participants’ most prominent impressions while using the prototype. Despite the potential to quantitatively analyse users’ inertial data alongside this evaluation, the overall aim to explore these approaches in practice – rather than proving clinical accuracy – may be supported by qualitative experience-based opinions, and so the additional time pressures and data protocols inherited by implementing such quantitative measures were not adopted.

B. Future work

Of the many potential branches for future work, clinical studies are among the most important. After putting the necessary ethical procedures in place, recruiting clinically hypervigilant participants would be the next significant step towards performing these studies. Then, a study procedure similar to the one conducted in this research could be carried out as usual.

Upon evaluating the subjective value of such technology to a hypervigilant population, the exploration of additional sensing types relevant to hypervigilance is essential when classifying its symptoms in a multidimensional and realistic manner. Combining this data through machine learning models is hypothesised to enhance affect recognition as demonstrated in related work, supporting the identification of associated behaviours in real time. Existing behavioural datasets, as well as data gained from users of the prototype with and without hypervigilant tendencies, will be fundamental in training these models.

After incorporating these models within a gamified VR environment, long-term future work should evaluate the effectiveness of such interventions over repeated and longitudinal use, alongside a large hypervigilant userbase to observe its psychological and behavioural effects on hypervigilance as a chronic condition.

References


[61] Magnopius UK. (2021) Biometrics level up vr and provide the next leap forward in human/computer interaction.


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