CASE REPORT

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Augmented Reality 3MDR Therapy for the Treatment of PTSD and Comorbid Moral Injury: A Case Study

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ABSTRACT

Rates of veteran suicide, post-traumatic stress, and moral injury remain alarmingly high and continue to rise. While virtual reality and augmented reality technologies have shown promise in improving post-traumatic stress disorder (PTSD) severity, research on these innovative methods is still limited. Multi-modal memory desensitization and reconsolidation (3MDR), a cutting-edge therapy that combines Virtual Reality Exposure Therapy or Augmented Reality Exposure Therapy with a "walk and talk" therapy, has demonstrated significant potential in enhancing participant engagement and substantially reducing symptoms of PTSD and moral injury among combat veterans. This case study highlights the novel use of 3MDR with an augmented reality head-mounted display for treating combat-related PTSD and moral injury, offering a new perspective on addressing these critical issues.

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INTRODUCTION

Veteran suicide remains a critical national crisis. The 2023 Department of Defense National Veteran Suicide Prevention Annual Report reveals a troubling rise in suicide rates among veterans: from 2020 to 2021, the rate for male veterans increased by 3.5%, while the rate for female veterans surged by 23.7%, though it dropped by 3.8% in the subsequent year.[1,2] The prevalence of post-traumatic stress disorder (PTSD) and moral injury (MI) among US veterans is alarmingly high. Post-traumatic stress disorder rates in the military are estimated to reach up to 30%, with combat veterans facing an increased risk of long-term trauma symptoms.[3,4] Additionally, nearly 42% of veterans deployed to combat zones encounter morally injurious events.[5] The comorbidity of PTSD and moral injury is strongly linked to suicidal ideation.[5-7]

Moral injury is a psychological trauma that occurs when a person's moral beliefs are profoundly violated, either through committing an atrocity, witnessing one, or experiencing betrayal.[8-10] While moral injury is not included as a defined, diagnosable condition in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5),[11] in recent years it has received considerable interest and recognition as a significant contributor to symptoms in combat veterans. It is characterized by intense feelings of guilt and shame and can lead to significant interpersonal and existential crises. These experiences often result in an increased risk of isolation, self-sabotage, and suicidal tendencies.[12,13,9,10] Research into the measurement and assessment of moral injury has shown that higher scores for morally injurious events are linked to the greater severity of PTSD symptoms.[14,7]

Research into veterans' perspectives on moral injury indicates that this issue is frequently overlooked or inadequately addressed in trauma treatment. Consequently, many veterans continue to suffer from moral injury symptoms even after completing treatment for PTSD.[15] Currently, there are few evidence-based practices that effectively address both PTSD and moral injury. Some promising results have emerged from case studies using interventions such as Prolonged Exposure,[16,17] Mindfulness,[18] and Acceptance and Forgiveness Therapy.[19] However, these interventions often face challenges

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with low retention rates. Additionally, engagement in treatments for moral injury and PTSD remains low among patients and research participants, largely due to societal and self-stigma, avoidance of trauma, and concerns about occupational repercussions.[20-24]

Recent years have seen the development of more innovative and culturally relevant therapeutic approaches that leverage advanced technologies like virtual reality and augmented reality. These modern methods not only capture the interest of the military population but also help overcome barriers to treatment. This paper presents a case study of a combat veteran with both combat-related PTSD and moral injury, detailing their improvement after undergoing treatment with the multi-modal memory desensitization and reconsolidation (3MDR) intervention using an augmented reality headset. This case study is part of an ongoing randomized control trial, the first of its kind, evaluating the effectiveness of augmented reality technology for treating PTSD and moral injury.

Virtual Reality Exposure Therapy

An innovative approach to trauma therapy is Virtual Reality Exposure Therapy (VRET), which can be delivered through either a head-mounted display or an immersive environment. Virtual Reality Exposure Therapy uses visual and auditory (and sometimes tactile or olfactory as well) cues to facilitate the participant's recall of traumatic experiences, reducing the risk of misremembering and the cognitive burden of imagining details. Functional magnetic resonance imaging studies have shown that VRET positively impacts brain regions typically affected by PTSD, such as the hippocampus, amygdala, and anterior cingulate cortex.[25,26] Recent research indicates that VRET may be more effective than traditional imaginal exposure therapy for service members with PTSD and comorbid conditions like depression, suggesting that virtual reality (VR) technology enhances participant engagement.[27,28] Various recent reviews have found that VRET is as effective as other commonly used psychotherapies for PTSD and other mental health conditions, and holds promise as an advanced treatment option.[29,30] However, authors have highlighted a significant research gap in VRET's safety and efficacy, noting only 10 published randomized control studies.[30]

Multi-Modal Memory Desensitization and Reconsolidation Therapy

Motion-Assisted 3MDR is an innovative PTSD therapy based on dual-task processing and working memory theories.[31,32] Key features of 3MDR include: 1) the use of augmented and virtual reality-based immersion, 2) concurrent physical activity, 3) continuous dialog and attendance with a therapist throughout the treatment period, and 4) lateral eye movement integrated in a more engaging manner than has previously been the case in "traditional" Eye Movement Desensitization and Reprocessing (EMDR) therapy.[33,34] Multi-Modal Memory Desensitization and Reconsolidation allows the patient to "step into the past," which been reported to assist in the reduction of symptoms related to helplessness and aid in the enhancement of self-empowerment.[33] Multi-modal memory desensitization and reconsolidation uses new technologies like VRET to reduce cognitive avoidance and enhance engagement, blending the appealing features and proven therapeutic principles of VRET and EMDR within the advanced Computer Assisted Rehabilitation Environment (CAREN). Originally designed for rehabilitation, the CAREN features a fully immersive 180° panoramic screen in front of a motion platform with an integrated treadmill.[35] The CAREN facilitates a multi-modal approach of 3MDR by enabling physical activity (walking) and simultaneous verbal engagement with a therapist to occur within a fully immersive virtual environment (VE) that can be individualized to enable deliberate confrontation, and in doing so, overcome physical and emotional avoidance, key features of PTSD.[33,32,36]

Multi-Modal Memory Desensitization and Reconsolidation in the CAREN has proved to be a successful method of intervention for combat-related PTSD, based on results from several case studies and randomized control trials. Several participants with treatment-resistant combat-related trauma experienced statistically and clinically significant drops in PTSD symptoms, with some individuals no longer meeting diagnostic criteria for PTSD, as measured by the Clinician-Administered PTSD Scale for DSM-5 (CAPS-5) or the PTSD Checklist for DSM-5 (PCL-5).[32,37,34,36]

Multi-Modal Memory Desensitization and Reconsolidation and Augmented Reality with the Augmented Reality Headset

While the administration of 3MDR within the CAREN appears to be a safe and effective treatment for combat-related PTSD, there are significant financial and logistical limitations. With few built across the globe and a multimillion-dollar price tag, the CAREN is not easily accessible. The need arose for a more cost-effective way to successfully implement 3MDR therapy while preserving the protocol and the use of innovative and captivating technologies. For this study, the authors sought to compare the effectiveness of the augmented reality (AR) headset, a much more affordable and feasible augmented reality head-mount display, to the CAREN for 3MDR.

The AR headset utilizes a visor to display the virtual images, allowing the user to see beyond the screen and maintain their peripheral vision. This is an added benefit for participants who may feel anxiety being fully immersed in a virtual reality environment. The 3MDR application and platform were reengineered to be run on an augmented reality gaming system. The use of augmented reality exposure therapy for the treatment of PTSD and MI is

unique, with little to no research published to date on the matter.[29,30]

METHODS AND PROCEDURES

Recruitment

Before participating in any study procedures, all participants provided written informed consent, which was administered by the principal investigator. Study participants consisted of male and female active-duty service members or veterans who had probable PTSD, as indicated by a PCL-5 score of at least 31. Those excluded from the study had moderate or severe TBI (as determined by the Ohio State University Traumatic Brain Injury [OSU TBI] Form), psychotic disorders including bipolar disorder, active suicidal or homicidal thoughts, recent use of benzodiazepines, inability to walk continuously at a normal pace for 60 minutes, were pregnant, or could not provide informed consent. The study took place at Uniformed Services University/Walter Reed National Military Medical Center, Bethesda, Maryland, USA. All procedures received approval from the institutional review boards at both Uniformed Services University and Walter Reed National Mlitary Medical Center in Bethesda, Maryland, USA.

Assessments

Prior to beginning the intervention, all participants completed a battery of baseline assessments including: Demographics, Medical History, PCL-5, CAPS-5, Patient Health Questionnaire – 9 (PHQ-9), Moral Injury Symptom Scale – Military Short Form (MISS-M-MSF), OSU TBI. Insomnia Severity Index (ISI), Neurobehavioral Symptom Inventory (NSI), and Brief Resilience Scale. These assessments, not including medical history and demographics, were administered again 2 weeks, 3 months, and 6 months post-treatment. During treatment, the PCL-5 was administered at sessions 6, 8, and 10 following the intervention.

Augmented Reality Software and Technology for Multi-Modal Memory Desensitization and Reconsolidation

With the advent of affordable and reliable AR and VR devices, VEs are increasingly used in the entertainment, education, training, and healthcare markets. In parallel, various devices/platforms have become available; however, support across multiple platforms is not often seen. Traditionally, when creating a VE for use on a specific device, the VE is inherently programmed for use on that device, an executable is then installed on the device, and users launch the program from within the device. In some instances, the software may be installed on a separate, tethered or untethered computer. Such variability across platforms makes it difficult for game designers to support a host of platforms and in return, limits the number of end-users that can experience the VE and the types of people that can operate the system. In certain markets, limited platform support becomes especially problematic. For example, in healthcare settings, patients who may benefit from a VE experience may have varying levels of mobility, device eligibility, and technology acceptance.

Naval Health Research Center developed a version of the 3MDR software that supports multi-platform use within a single software application. The software hosts the virtual environment and all programmed code to control the VE. Specific scripts are designed to determine an end-user's platform selection and run appropriate code for that device, such as that for the CAREN or the AR headset.

A "master" executable is placed on the master device (e.g., computer or tablet). When the "master" software is launched by a user, he/she selects which platform they are trying to connect to. For tethered devices (i.e., screen-based setups, tethered AR or VR systems), the program will launch from the master device but can be visualized on the selected platform. The clinician/operator of the master device can then control the program being run on the selected platform (e.g., run the different phases of 3MDR, set parameters/environment settings, etc.), allowing the ability for the clinician/operator to control the environment without disturbing the patient user experience.

Intervention

Ten 90-minute intervention sessions were conducted, where the therapist and participant addressed images representing the trauma. Each session had 3 stages: warm-up, intervention, and cool-down. In the warm-up phase, the participant wore the augmented reality headset and walked on a treadmill while listening to a chosen piece of music intended to evoke the trauma emotionally and mentally. They experienced a bright environment with a blue sky and a light honeycomb path ahead of them (Figure 1A).

After the first song ended, the screen shifted to a dark sky, a red honeycomb path, and metal doors (Figure 1A), marking the start of the intervention phase. The participant walked through 2 sets of doors and hallways until a selected image appeared. The therapist then asked the participant to describe the image and discuss its meaning, associated memories, and emotions. Key emotional terms, or "Associations," were overlaid on the image, which the participant read aloud (Figure 1D). In the Eye Movement phase, a red ball with changing numbers bounced across the screen for 30 seconds (Figure 1C). Participants read the numbers aloud, then rated their discomfort via a Subjective Units of Distress Scale (SUDS) from 1 to 10. This process was repeated for up to 4 images per session.

After the final image, the participant moved to the cool-down phase, where their last SUDS score was recorded.

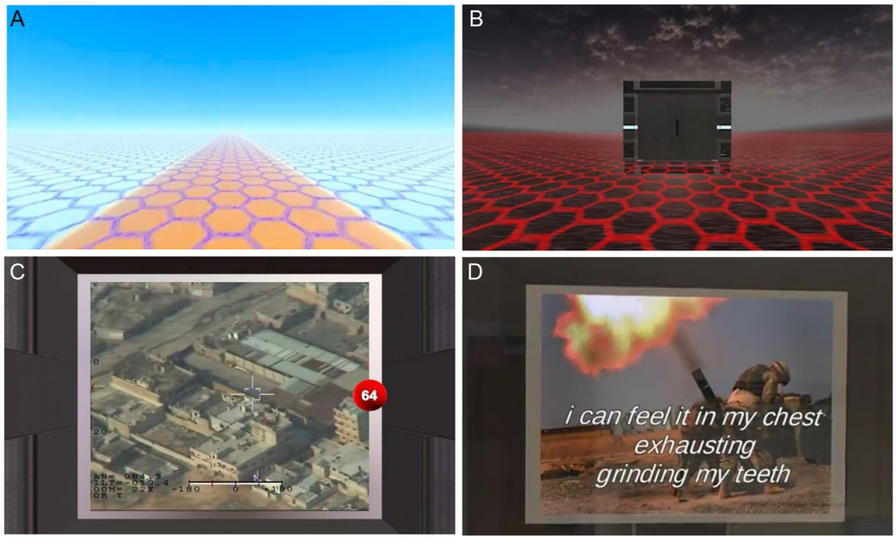

Figure 1. A-D. Images captured from the 3MDR Software. Axial (A) the blue honeycomb scene is shown during the warm-up and cool down phases. Coronal (B) the dark honeycomb scene is shown when entering the intervention phase. Axial (C) EMDR begins after discussing each image in the intervention phase. Coronal (D) view from the AR headset during the 3MDR intervention.

The visual changed back to the blue sky and honeycomb path, and the second piece of music was played in full to help the participant decompress and return to the present. The session concluded with a debriefing between the participant and therapist, followed by journaling any remaining thoughts or emotions, or reflecting on the day.

The final consolidation session involved the therapist and the principal investigator. Prior to this session, the participant completed a series of questionnaires. The therapist reviewed the participant's progress, noting significant improvements in symptoms, changes in associations and SUDS with specific images, and key points from their written reflections. The session concluded with a discussion about any additional therapy that could further enhance the progress made and how to access it.

Case Report

We report the experience of the first participant randomized to the augmented reality head-mounted display (AR-HMD) treatment group in a 3MDR study comparing delivery via AR-HMD with delivery via CAREN. Consent to use data in this case study was obtained directly from the participant, who had also provided informed consent to participate in the study. Prior to participating in any study procedures, the participant provided written informed consent, administered by the principal investigator.

George

George is a 39-year-old male who served in the United States Army for 20 years, retiring in 2022. George was deployed to Iraq with the 82nd Combat Aviation Brigade. He was also heavily involved in personnel recovery efforts during the withdrawal from Afghanistan in 2021, assisting Afghani families and allies to seek asylum during the fallout. At the start of George's participation in the study, he was married but acknowledged there was turmoil in the relationship and mentioned a history of suicidal ideation. He also acknowledged estranged relationships with many family members, including his mother and father. George was grappling with his sense of identity after recently retiring, and his transition out of the military was taking a social, professional, and emotional toll—a topic of significant focus during therapy. George had completed several other interventions in his efforts to treat the combat-related PTSD and MI, including Prolonged Exposure therapy, but failed to see lasting improvements in his symptoms.

Trauma Descriptions

During the first 2 preparatory sessions, George and the therapist discussed which traumas he wanted to address in the intervention and selected images to trigger memory recall. They reviewed several traumatic and stressful events, including combat exposures and his role in the withdrawal from Afghanistan.

The primary index trauma was an incident from George's deployment in Iraq in 2004. George recounted that he was manning the turret of an up-armored vehicle, providing security on a city road at night. When a school bus approached at high speed, George fired a warning shot, but the bus continued toward them. After a second warning shot, which also failed to stop the bus, George was ordered to disable it and the driver, fearing it might be a vehicle-borne improvised explosive device. He fired continuously at the bus with a 50-caliber weapon, hitting both the front and side. George later described feeling as if he had committed a grave crime, uncertain whether the bus contained children. He referred to himself as a "monster" and struggled with the violent action he had

taken. This event led George into a profound moral crisis, causing him to question his own goodness and that of those around him.

Picture Selection

As previously mentioned, participants were asked to choose images that represented their traumatic experiences, each rated on a SUDS from 1 to 10. These images ranged from Google Maps views of the trauma location to personal photos of attackers, injuries, or casualties. For George, his selection included a mix of images from his deployment, such as photos with his unit and him in the Iraq desert, as well as recent images of his family, work life, and retirement ceremonies—reflecting his struggle with identity during his transition out of the military (see Figure 2). He also included images he received while aiding in efforts to help allies seek asylum from Afghanistan.

For the primary trauma, George and the therapist identified an image on Google that elicited a strong emotional response related to the bus incident. The chosen image, shown in Figure 2, is a stock photo of an American yellow school bus filled with children and surrounded by waving parents. This image received a high SUDS score of 9, indicating a high level of distress.

RESULTS

George completed 3 preparatory sessions and 10 90-minute active intervention sessions of 3MDR using the AR headset. At baseline, George's PTSD severity score, measured by the PCL-5, totaled 60. By session 6, there was a steep decline in George's PTSD symptoms, with his score dropping by nearly 50%. Following session 8, the participant no longer met the clinical cut-off for PTSD on the PCL-5 with a score of 27. By the post-treatment follow-up, the symptom score decreased further to 14. A restoration of positive emotions was also observed on the PCL-5, particularly for the question, "Trouble experiencing positive feelings (such as being unable to feel happiness or have loving feelings for those close to you)?" At baseline, George reported experiencing this difficulty "quite a bit," whereas by the post-treatment follow-up, his response was "not at all." Additionally, the intervention had a positive impact on decreasing symptoms of moral injury. Using the MISS-M-SF, George's baseline was 75 out of 100, with 6 items scoring above an 8 out of 10, indicating a need for clinical intervention.[38] At the post-treatment follow-up, the MISS-M-SF total declined by over 50% to 36, with only 1 item scoring an 8. A crucial symptom decrease noted on the MISS-M-SF was for statements related to self-blame and guilt—"I feel ashamed about what I did or did not do during this time" and "I feel guilt over failing to save the life of someone in war." At baseline, George responded "strongly agree" to both statements, but at the post-treatment follow-up, both responses changed to "strongly disagree," indicating a release of the guilt he had felt regarding his actions in combat. Improvements were also seen in George's self-reported scores for insomnia, depression, and neurobehavioral symptoms as measured by the ISI, PHQ-9, and NSI (Figure 3), with no suicidal ideation reported on the PHQ-9 at post-intervention. Considerable improvements were also seen in the pre- and post-SUDS assigned to the images. By the end of treatment, each

Figure 2. Examples of distressing images from participants' photo inventory.

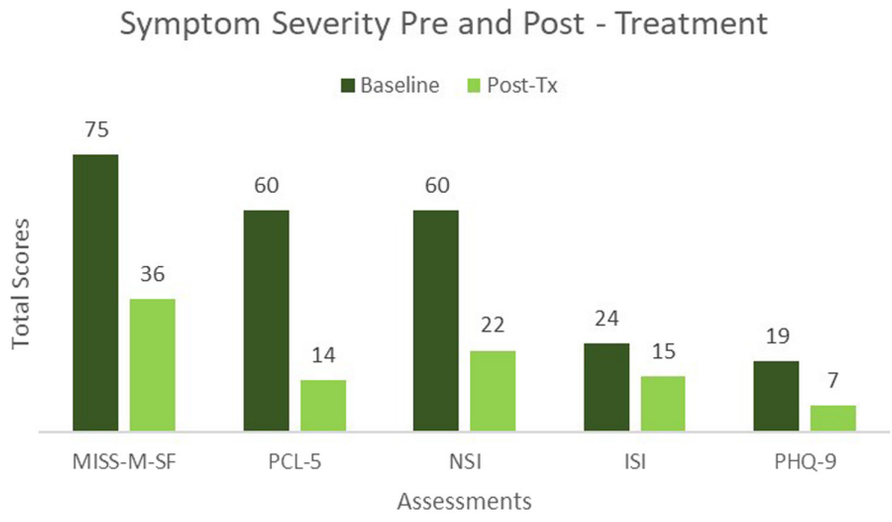

Figure 3. Graphic of pre and post treatment assessment totals. MISS-M-MSF, Moral Injury Symptom Scale – Military Short Form, PCL-5, PTSD Checklist for DSM-5, NSI, Neurobehavioral Symptom Inventory, ISI Severity Index, PHQ-9, Patient Health Questionnaire – 9.

picture in his photo inventory was rated with a SUDS of 1 or 2. Even positive images that initially had a SUDS rating of 3 or 4 had decreased to 1 by the post-treatment follow-up, indicating a more hopeful and content outlook.

Qualitative measures revealed improvements in George's overall perspective on his sense of self, life, and relationships, demonstrating the intervention was helpful in improving some of the key features of PTSD and moral injury, such as isolation, negative beliefs about self and others, and personal and existential crisis.[39,13,9,10] Clarity in perspective on the traumatic event itself was also established, as it was revealed while in session that no one was harmed in the bus incident. These improvements were seen in his journal reflections and throughout his correspondence with the therapist. Notable quotes pulled from George's messages and journal entries are provided below:

"Today helped me to realize, we don't have to go backward. Depression they say is being mentally in the past and anxiety in the future. This treatment/research study has really helped maintain a current perspective."

"Moving past the past, getting over myself, and moving forward."

"Emailed my mom and said simply the past is the past…Intangible stuff, forgiveness, maturity… dealing with stuff and getting to present…"

DISCUSSION

Multi-Modal Memory Desensitization and Reconsolidation, when delivered via the augmented reality headset, proved to be a viable and effective approach for addressing combat-related PTSD and comorbid moral injury in this participant. He demonstrated substantial improvements across all study assessments, with most scores decreasing by 50% by the post-treatment follow-up. The most significant improvements were evident with regard to PTSD and moral injury symptoms, with the participant no longer meeting criteria for PTSD as early as the 8th intervention session based on the PCL-5, and with the MISS-M-SF score dropping from 75 to 36 and only 1 item requiring clinical attention, down from 6. The most notable symptom improvements were seen in those related to self-blame, negative beliefs about the self and the world, and difficulties feeling happiness, interest, and social connection or closeness. Throughout the study, the participant consistently reported enjoying the process and chose to complete all 10 sessions. The post-session journals revealed that the participant found the open dialogue with the images to be instrumental in developing a new perspective on both his sense of self and his past traumas, helping to alleviate the moral weight of his actions during combat. By focusing on the contrast between the past and present, the sessions allowed George to recognize his personal growth, despite past transgressions, and to embrace who he has become. Additionally, the participant highlighted the positive influence of movement and physical activity on the success of the therapy, fostering healthier habits and increased motivation beyond the sessions.

This case study underscores the potential of 3MDR with AR delivery for PTSD and moral injury. Enhancing the accessibility of this intervention could significantly reduce barriers to care for combat veterans by making this technology available in clinics, military treatment facilities, and potentially in combat settings for immediate trauma intervention, since an augmented reality headset only costs $3500, as opposed to more than $1 million for the CAREN. While further study is needed, this case report demonstrates that AR-HMD-delivered 3MDR is both engaging and effective in addressing combat-related PTSD and moral injury.

Limitations

Moral injury is a relatively new concept that is increasingly gaining attention in the field of trauma intervention.[8] However, it is not yet recognized as a formal diagnosis in the DSM-5[11] and lacks established diagnostic criteria or cutoffs, complicating efforts to accurately track and report progress.

The results of this case study reflect the progress of the individual participant and should be interpreted with caution. To establish the effectiveness and potential of this treatment more reliably, a randomized controlled trial is needed. Fortunately, this case study is part of a larger, ongoing randomized controlled trial aimed at evaluating the impact of 3MDR with augmented reality on PTSD and moral injury.

Data Availability Statement: The data that support the findings of this study are available upon request from the corresponding author.

Ethics Committee Approval: The study design was approved by the Institutional Review Board at the Uniformed Services University (Protocol No: USUHS.2021-076 Date: 2021), and was posted on clinicaltrials.gov, # NCT05244564.

Informed Consent: Written informed consent was obtained from the patient who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

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