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Virtual reality immerses you in your mind: the experience and stress-reduction benefits of VR mindfulness modules in persons with TBI

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ABSTRACT

Objective: This pilot study tested the feasibility and stress reduction effectiveness of a one-time virtual reality mindfulness module (VRMM) in individuals with mild-to-moderate traumatic brain injury (TBI).

Methods: Thirty-eight participants participated in a pilot study utilizing a mixed methods convergent parallel design. Pretest and posttest stress levels were collected; participants engaged in a brief 4-question qualitative interview. Mann Whitney U and Wilcoxon Signed Rank Tests were used. Qualitative analysis utilized grounded theory.

Results: Post-VRMM, two-thirds (24) of participants had a statistically significant decrease in stress levels. A key qualitative finding indicated that participants found the immersiveness and realism of the VR environments helpful in compensating for cognitive deficits resulting from TBI. There were no adverse side effects reported, indicating that well-designed VRMMs that minimize motion-induced adverse effects are well tolerated in persons with TBI.

Conclusion: A guided mindfulness activity in a VR environment was well tolerated, and participants overall found VRMM effective in reducing stress levels. VR-based environments have potential to harness guided mindfulness practice and may support persons with TBI to enhance concentration. Further application of this technology in TBI rehabilitation is promising and warrants future research to explore the benefit of VR in improving rehabilitation outcomes.

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Mindfulness; traumatic brain injuries; virtual reality; mixed methods; rehabilitation

Introduction

Research has identified numerous benefits of mindfulness practice. As popularized by Kabat-Zinn (1), a well-known definition of mindfulness in a clinical context is paying attention in a special way: on purpose, in the present moment, and without judgment. According to a recent systematic review, mindfulness-based interventions in a rehabilitation context were efficacious in ameliorating various psychological symptoms, including fatigue, as well as self-reported cognitive function and specific neurological symptoms; significant benefits were found for objectively measured cognitive outcomes as well (2).

Numerous benefits have also been found regarding specific application of mindfulness activities to persons with TBI. Mindfulness was reported as beneficial in coping with emotional and cognitive consequences following brain injury (3, and showed promise for improving cognition, self-monitoring, and mood (4). Additionally, mindfulness interventions may improve the quality of life and/or depression symptoms of persons with TBI (5) and, according to a systematic review, 75% of the outcomes of multiple research studies indicated significant and/or positive results in using mindfulness with persons with TBI (6). Furthermore, mindfulness-based interventions for persons with TBI are likely feasible and effective and, compared to a control group, have been linked to significant reductions in chronic stress, depressive and general symptoms (7).

In application to TBI rehabilitation, Virtual Reality (VR) has demonstrated a number of benefits. VR is defined as 'a computer-generated digital environment that can be experienced and interacted with as if that environment were real' (8). VR can mimic everyday contexts, creating a positive, motivating and enjoyable learning experience, while possibly improving generalizable cognitive skills (9–12). VR also has potential to provide effective assessment and rehabilitation among those with TBI (9–12).

In TBI rehabilitation, VR activities have significantly improved cognitive functioning, mood, cognitive flexibility, and selective attention (13), as well as memory and executive function (14). In a literature review of 11 studies, VR use in TBI (most frequently implemented to address gait or cognitive deficits) consistently yielded clinical improvements (15). Additionally, a recent systematic review found that VR interventions significantly improved neurocognitive performance in 10 of 13 studies (10). There has also been research examining VR and mindfulness in persons without TBI. Recently, Seabrook et al. (16). found that VR can support mindfulness practice by inducing positive affect and enhancing mindful presence. In sum, there are indications of significant benefit for persons with TBI in utilizing mindfulness exercises, and in receiving VR interventions. However, there have been no studies to date that have examined the effects of the combination of mindfulness interventions on a VR platform in persons with TBI.

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Methods

A mixed methods convergent parallel design was implemented to explore the feasibility and effectiveness of VR mindfulness modules (VRMM) with persons with TBI. Using subjective units of distress scale (SUDs; 0–10 Likert scale rating) (17), pretest and posttest stress levels were collected, and participants engaged in a brief 4-question qualitative interview (see Appendix A) after VRMM administration. The Biomedical Research Alliance of New York (BRANY) provided Institutional Review Board approval (Protocol #22-060-1103, Event ID #198748).

The intent of this pilot study was to determine the immediate stress reduction benefits of VRMM. Various measures of stress were considered, however, given the exploratory nature of this study a SUD scale was utilized, relying on a colloquial conceptualization of stress as understood by the participants. Stress is a term that references sympathetic arousal, commonly known as the 'flight or fight response,' comprehensively described by Bay et al. (18).

Participants

Two brain injury rehabilitation providers, one in New Jersey and one in Pennsylvania, granted permission to recruit participants from their rehabilitation locations. Participants were required to have a TBI and be between 18 and 70 years of age, and were receiving residential brain injury services or long-term attendees of brain injury day programs. Persons with non-TBI or severe TBI, as well as individuals with a medical decision maker or guardian were excluded. Convenience sampling was used to locate participants. Participating sites selected potential participants who met inclusion criteria based on their medical history.

Procedures

Two participating brain injury rehabilitation providers identified potential participants who met the inclusion and exclusion criteria. Potential participants met with researchers once at provider sites to learn about the study and review the informed consent form. After participants provided informed consent, the researchers proceeded.

Participants choose from two VRMM options (beach or mountain scenes, each lasting approximately 4 min) using the Oculus Quest 2 platform. Both VRMM included a female voice providing instructions on how to breathe, intermittent reminders to breathe, and to focus on certain aspects of the VR environment, i.e. watch the sun rise from the ocean. The VRMM were designed to curtail movement in the VR environment, so as to minimize the likelihood of VR vertigo, which can affect persons with TBI (17–19). The device was disinfected, and a hygiene cover was applied before each use. Safety protocols were reviewed with each participant, such as remaining seated and how to discontinue VRMM. The Oculus was cast to an external screen to monitor experiences in the VR environment for quality assurance. Participants had the Oculus fitted to their heads, and they were oriented to its use; they were also educated about what to expect in a VR environment. Participants rated in-the-moment stress levels using a Likert scale (0–10) before and after the VRMM. Additionally, after the VRMM administration, participants rated their likelihood of using a VRMM in the future (Likert scale 0–10), and they responded to four open-ended questions regarding their experience utilizing the VRMM. The posttest survey took approximately 10–20 minutes to complete, and the researchers transcribed the responses. No compensation was offered; all procedures for consent and confidentiality were followed.

Data analysis

A Wilcoxon Signed-Rank Test was utilized to determine the difference between stress pretest and posttest scores. A Mann-Whitney U Test was conducted to examine the differences in pretest and posttest scores between the beach and mountain VRMM. Researchers calculated the difference in pretest and posttest scores for each participant and employed an additional Wilcoxon Signed-Rank Test to examine the change in pretest and posttest scores between those who received the beach versus mountain VRMM.

Data from the brief open-ended interviews (see Appendix) were analyzed using a grounded theory approach (20,21). Qualitative data analysis was conducted concurrently with data collection; line-by-line coding was performed to develop open codes and *in-vivo* codes (20,21). A systematic approach was utilized to identify patterns using constant comparison in the development of focus codes, some of which were *in-vivo codes*, to then generate themes (22). An audit trail tracked how 957 open codes were compared and sorted leading to 14 focused codes and, after further comparison, 6 provisional categories. A code book was developed to further define themes and supporting codes, resulting in the emergence of three final themes. Several strategies were utilized to ensure rigor of qualitative data analysis: memo writing (23,24), peer debriefing (21), negative case analysis (21,23), auditability (21,25), and examining transferability and credibility (25). Credibility was evident in the support of the themes by the literature. Participants' experiences were consistent across sites and TBI severity, thus demonstrating transferability. Four participants who denied any post-stress reduction but identified VRMM as calm and relaxing, had their data included as negative case analyses (see Table 1).

Results

Quantitative findings

Pretest stress level scores ranged from 0 to 10 with a mean of 3.42 (Mdn=3.5). Five (13.2%) participants rated stress levels between 7 and 10; 14 (36.8%) rated stress levels between 4 and 6; 11 (28.9%) rated stress levels between 1 and 3; and 8 (21.1%) rated a stress level of 0. Posttest scores ranged from 0 to 7 with a mean of 1.76 (Mdn = 1.5). After engaging in VRMM, only one (2.6%) participant rated their stress level as a 7 or higher; 6 (15.8%) participants rated stress levels as 4 or 5; 13 (34.2%) rated stress levels between 1 and 3; and the majority (18; 47.4%) rated a stress level of 0. Eight

Table 1. Demographic characteristics.

Age, *mean* (SD)*	*46.8* (11.4)
Gender, *n* (%)	
Man	*30* (78.9)
Woman	*8* (21.1)
Race, *n* (%)	
White	*32* (84.2)
Black	*4* (10.5)
Hispanic/other	*2* (4.8)
Site, *n* (%)	
Site 1	*9* (23.7)
Site 2	*29* (76.3)
Module, *n* (%)	
Beach	*18* (47.4)
Mountain	*20* (52.6)
VR Duration (in seconds), *mean* (SD)	*292* (48.3)

*One participant was 71 years old, which was a minor deviation from the inclusion criteria reported to the IRB.

participants rated their pretest stress level a 0. Additionally, stress levels (greater than zero) of five participants remained unchanged from pretest to posttest (see Figure 1). A Wilcoxon Signed-Rank Test indicated that the score decline from pretest to posttest was statistically significant (see Table 2 & Appendix B).

There were no significant pretest or posttest score differences in comparing the beach and mountain module groups (see Appendix C). Additionally, there was no significant difference in the change of the pretest and posttest scores between the two VRMM groups (see Appendix D). These findings indicated similar stress reduction benefits, regardless of which VRMM was chosen.

Qualitative findings

Three themes emerged: (1) emotional experience (2), virtual reality immerses you in your mind (3), considerations for future use.

Table 2. Stress pre-test and post-test scores.

	Pretest			Posttest			
Participants ($n = 38$)	Median	Mean	SD	Median	Mean	SD	Significance[a]
	3.5	3.42	2.74	1.5	1.76	1.99	$p < 0.001$

Abbreviations: SD, standard deviation.
[a]Using a Wilcoxon Signed-Rank Test.

Emotional experience

34 participants endorsed that VRMM provoked relaxation and tranquility; as one participant described, it 'made you open your eyes and feel the quietness and feel how peaceful it was.' Participants shared that VRMM allowed them to 'get away' and to 'not be here.'

Participants endorsed a reduction in stress, referring to the relaxing experience as feeling 'a little Zen.' A participant further elaborated how VRMM reduced stress, 'It made me stop thinking about the other stressors – all the stress building up over the years – they went away for a bit.' Although six participants denied stress reduction, four of these participants identified VRMM as relaxing and calming. One participant explained that VRMM was too short to fully benefit, 'I appreciated the way it was meant to incite a relaxed state, but it was far too short for me to feel any sustained mindfulness.' The two participants who did not find the VRMM relaxing nevertheless indicated that they would use the VRMM again in the future.

Several participants reminisced after engaging in VRMM. One participant shared nostalgic memories of their beach honeymoon, while another participant recalled, 'I have a house at the shore and whenever I … go down and walk on the beach, and I think of people, and I reminisce.' However, one participant lamented that their behavior negatively

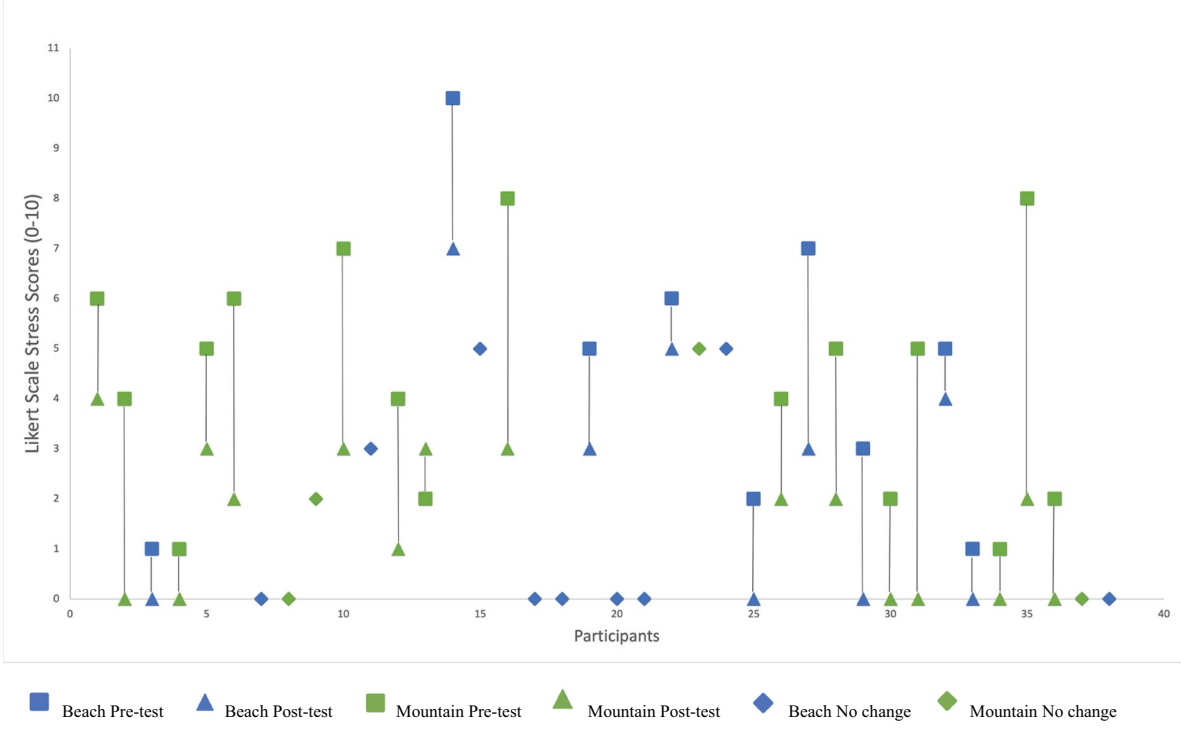

Figure 1. Individual pre- and post-test scores comparisons.

impacted their well-being: 'I would not have acquired a TBI if I hadn't been on drugs at the time or drinking at the time. I would've been safe in my house.'

'VR immerses your mind'

35 participants described VRMM as an immersive experience. In 32 instances, participants felt as though they were transported to another reality. One participant exclaimed, 'It's crazy how life like this is!' Participants further elaborated, 'I felt like I was sitting at the beach watching the waves . . .' and, 'it felt like I was really standing in front of a mountain.' Interestingly, some participants noted that VRMM provided opportunities for new experiences. A participant who had never witnessed mountains before commented, 'If I'd never been to the mountains, which I haven't, it gives me the closest reality of being near the mountains.' Only two participants did not find the environments to be realistic.

As participants had their initial glimpse of the environments, participants often exclaimed phrases such as, 'holy mackerel!' and, 'oh heck!' Some participants wanted to interact more with the environment, such as 'wandering around the garden and pond' or 'wish I could've sat in the hammock.' Others fantasized about things they would do if they were actually there, e.g., getting a massage, or looking for hermit crabs at the beach. One participant imagined dining at a café along the boardwalk. Some participants, particularly those who chose the beach, desired additional sensory experiences (e.g., yearning to feel the water or smell the ocean).

Participants commented 77 times about admiring the scenery. Some participants compared the imagery to a movie or 'staring at a beautiful picture.' The virtual environments were described as beautiful, breathtaking, and gorgeous; one participant proclaimed, 'You don't often get to go to an environment like that!' Participants praised the carefully constructed details and color palette of the environments (e.g., 'this elaborately designed beautiful scenery'). One participant shared how 'the detail shocked me – even the grains of the sand,' and further elaborated, 'it's creepy – it was so detailed.' Participants found the virtual environment sounds to be integral to the realism, commenting on hearing the waterfall or the waves in the mountain and beach VRMM, respectively.

Thirty-two participants spoke about benefits of having an immersive environment with both audio and visual elements. This incorporated more of their senses, 'You use more of your senses. You get more out of it . . . it wouldn't be as good without the visuals.' Numerous participants commented that the fully immersive experience made the mindfulness activity more effective and enjoyable; and because of this, they were better able to relax: 'I've done [mindfulness] without visuals before and it wasn't as relaxing.' A participant shared that VRMM was 'way better 'cause you get to see the atmosphere – it takes you from visualizing it to actually being able to look around . . . way better than just picturing.' One participant was highly satisfied:

> This was by far the best [mindfulness experience] – you had something to watch while you were doing mindfulness. You weren't staring in the room – you had something actively to do and participating. You weren't just told to close your eyes and imagine things. . . . Thank you. It's so much better than someone just talking and talking.

Some participants shared that, post-TBI, it was difficult to conjure up mental imagery, and they expressed gratitude that virtual imagery was provided: 'Sometimes people who have brain injuries can't use their imagination as well as other people.' Another participant called the VRMM 'a triple threat,' and further elaborated, 'It gives you the visual of what you're hearing instead of using your imagination. When you see it, you can imagine it a little more.'

Twenty-seven participants found that it was easier for them to focus in the VRMM compared to audio-only mindfulness activities. Those same participants emphasized the VRMM increasing attention 68 times. A participant explained, 'This is 100× better – because it sustained my focus.' Another fittingly shared, 'It immerses you in your mind. . . [in] mindfulness you have . . . a difficult time focusing and clearing my head- this easily cleared my head.' Participants further explored that VRMM held their attention throughout, therefore promoting increased focus: 'It had me focusing on something without even knowing.' One participant further commented, 'This would keep your attention a lot more than just listening. Someone like me, if I'm sitting listening to something and someone is talking over there, that's no good to me.' In contrast, one participant felt conflicted about the detailed virtual environment, 'Being submerged in this new environment was almost distracting to the mindfulness;' although 'it prevented me from going into a deep tranquil state. . . at the same time it was so calm.'

Participants addressed how VR immersion eliminated distractions and anchored their focus: 'If it's all virtual reality, it's everything you see and so you can't look away.' Participants reflected on how this contrasts with the typical disruptions of practicing mindfulness in their day programs: 'People talk all the time during the mindfulness and they kind of mess it up for other people. . . [VRMM] would help if you just had that on and it [was] blocking out them.' Another participant agreed: 'I feel like I'm alone in my own room [with VRMM], and without it everyone is still talking and taking your mind off what you're supposed to do.' The elimination of background noises and being unable to look away made it easier to focus; hence, participants were fully engaged in- and benefitted from- the VR mindfulness activity.

The voice that provided directions during VRMM was described as 'very pleasant.' Several participants preferred a female versus a male voice. Most participants appreciated having auditory instructions in a 'calming voice,' which they found contributed to sustaining their attention. Participants shared that the guided instructions 'made it easier' and 'showed me what to focus on.' In particular, the voice quality and amount of instruction was deemed to be appropriate: 'the way she spoke made you feel relaxed,' and the voice 'seemed to drift in and out.' Two participants who previously practiced mindfulness commented that guided instructions were unnecessary, while two other participants were indifferent or neutral.

Considerations for future use

Thirty-six participants endorsed interest in future VRMM use, and most provided only positive feedback. One participant commented, 'It worked very well. It was virtual reality but it was *real* virtual reality – it actually worked. It wasn't like

a gimpy version that doesn't really work, like a lot of things that you might find on the market.' Only a few had constructive feedback, e.g., regarding different expectations (of a more interactive experience, or of how mountains should be depicted), of being disturbed by not seeing one's hands, and by distractions during the experience (i.e., a visible gap at the bottom of the device, and a red dot indicating screencasting). A few participants shared that the headset felt heavy, and one found that the device's weight was distracting.

Few participants had suggestions on how to better develop the technology for persons with TBI. The most common request pertained to a larger selection of environments: 'Other [persons with] TBI might have a different preference for what is relaxing for them.' Anticipating this, a question about possible alternative relaxing environments was included in the posttest. The four commonly suggested relaxing environments were mountains, forest/cabin, ocean/beach, and open field/park. Some requested a more physically interactive experience in the VR environment.

Discussion

Post-VRMM, two-thirds (25) of participants had a statistically significant decrease in subjectively reported stress relief. Of the remaining third, most (8) had a 'floor effect' of pretest ratings of 0, followed by posttest ratings of 0. Interestingly, the 8 with a floor effect all reported beneficial effects pertaining to relaxation, and/or they had interest in using a VRMM again. Five participants with pretest stress levels above 0 had posttest ratings that were unchanged; however, all reported that the VRMM was relaxing. Stress reduction benefits for the beach and mountain VRMM were not dissimilar, as there were no significant differences between their posttest stress score changes.

Most participants endorsed that VRMM induced relaxation, tranquility, and calmness, which corroborated the quantitative stress reduction findings. This is consistent with prior research on beneficial results from mindfulness in persons with TBI (3,4). Furthermore, these findings align with Bay and Chan (7), who found that mindfulness-based interventions for persons with TBI are feasible and effective, considering factors such as significant reductions in chronic stress and other symptoms.

A key qualitative finding indicated benefits to using VR in persons with TBI. Participants endorsed that the immersiveness and realism of the VR environments ostensibly compensated for cognitive deficits, e.g., by limiting distractions and promoting attention. Participants cited how these factors enhanced focus and engaged them in the mindfulness activity; in turn, this may have increased the effectiveness of the stress reduction activity. Participants also mentioned that a mindfulness activity - incorporating both visual and audio elements - was more effective compared to common audio-only mindfulness activities. Participants found this helpful, as several commented that persons with TBI often have a hard time following guided imagery due to post-injury issues with visual imagination. These findings corroborate the results of Seabrook et al. (16), which demonstrated that VR supports mindfulness practice by enhancing state mindfulness and inducing positive affect. Indeed, our findings suggest that VR may address challenges of mindfulness practice – especially exacerbated by cognitive issues in persons with TBI (e.g., diminished concentration, increased distractibility, etc.) – by creating a 'sense of presence' within a TBI-friendly tailored virtual environment, allowing users to attend to visual/auditory anchors of their choice, and by diminishing mind-wandering due to extraneous stimuli (16). As there were no adverse side effects reported, well-designed VRMMs (designed to minimize motion-induced adverse effects by eliminating excessive movement in the VR environments) are well tolerated in persons with TBI. This finding is consistent with prior research showing the positive results of utilizing a VR platform in TBI rehabilitation (13,14). Furthermore, the VRMM truly engaged participants through a modality that they found pleasant and beneficial in promoting relaxation.

Future interventions should continue to leverage and utilize the VR format, as it appears desirable and well tolerated in persons with TBI. Additionally, use of VRMM in persons with TBI is promising given the participants' reports of anchoring attention (visually and/or auditorily) and eliminating ambient distractions. VR has a unique ability to harness guided mindfulness practice with tailored virtual environments, which can support persons with TBI to focus on the present moment (16). A main limitation of this pilot study was the relatively small sample size and the use of convenience sampling, limiting the generalizability of these findings. Future research is needed to further explore VRMM benefits and better understand the differential efficacy of VR use in persons with TBI. As stress was addressed in a general way in this pilot study, future studies on the benefits of VRMM should consider measuring stress with various psychometrically sound scales, such as the Perceived Stress Scale. Additional recommendations for future research include exploring participants' levels of cognitive and emotional function at baseline for comparison when examining post-intervention changes, as well as the duration of stress reduction effects. Future studies can also benefit from utilizing physiological measures to further determine the effectiveness of VRMM on physiological stress as well as perceived emotional and cognitive stress. To examine if those with TBI experience greater benefit from the combination of visual *and* auditory VR environments, especially compared to a non-TBI group, future research could use a non-TBI control group, as well as a TBI control group receiving a non-VR (audio-only) mindfulness intervention.

Conclusion

This mixed methods pilot research study addressed the paucity of research on the combination of mindfulness activities implemented in VR in persons with TBI and further examined the feasibility and potential for VR application in TBI rehabilitation. This study, corroborated by the quantitative and qualitative findings, suggests the potential for the relaxation enhancing and stress-reducing benefits of mindfulness activities in a VR environment. Indeed, the majority of participants experienced stress reduction and/or a calming effect as a result of engaging in a VRMM. Furthermore, participants endorsed that the VRMM immersive experience may have mitigated

cognitive issues in persons with TBI (e.g., distractibility and concentration), which may have empowered them to more fully engage in, and benefit from, the guided mindfulness activities. Future research is warranted to further examine the potential benefits and efficacy of mindfulness utilizing a VR platform in persons with TBI.

In conclusion, VR environments have potential to harness guided mindfulness practice, which participants felt enhanced concentration in the present moment. The VRMM experiences were well tolerated, and no adverse effects were noted. The promise for this technology in providing clinical benefit in TBI rehabilitation settings is noteworthy.

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