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The effectiveness of immersive virtual reality (VR) based mindfulness training on improvement mental-health in adults: A narrative systematic review

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ABSTRACT

Objective: In recent years, digital techniques, such as virtual reality (VR) has been employed in tandem with more traditional psychological interventions. The aim of this study is to investigate whether VR-based mindfulness training can improve mental health outcomes, and notably mindfulness levels amongst adults. In addition, this review seeks to summarise the various designed VR scenarios, as well as those elements around VR that may assist people in practising mindfulness and meditation.

Methods: The search for eligible studies for inclusion was conducted via the following databases: the Applied Social Science Index & Abstract (ASSIA), PsychINFO, Medline, EMBASE, and the Web-of-Science Core Collection. Only experimental studies were eligible for inclusion, and specifically, those that compared the effectiveness of mindfulness training using immersive VR (on the one hand) with a control condition.

Results: This search generated 2523 articles published between 2016 and 2022, and of these, 106 were assessed for eligibility. This review included seven studies, with a collective total of 798 participants. VR-based mindfulness training has been shown to be more effective than conventional mindfulness – it improves levels of mindfulness and meditation experience; but also shown to reduce anxiety, depression, improve sleep quality, emotion regulation, and generate mood improvement. VR-based mindfulness training frequently contains natural 'environmentally relevant' elements, such as forest, grassland, caves, sea, etc.

Conclusions: This review suggests that using VR to assist mindfulness training is an effective and innovative way to improve mental health conditions within the adult population. Further directions and limitations are discussed.

Introduction

Mindfulness, as a concept, originated with Buddhism, and it references a mental state whereby one focuses one's attention on the present moment, with non-judgmental awareness.[1] Mindfulness is, moreover, typically divided into a mindful state and trait.[2] The first component refers to short-term or transitory levels of mindfulness, which may be cultivated through the practice of meditation. The second describes one's personal characteristics insofar as they relate to mindfulness.[2,3] Being mindful has been demonstrated that benefits one's emotions in a 'non-judgmental' way, which is achieved by adjusting one's breathing, training oneself to be 'present in the moment', and adopting attention-focused mindfulness practices to reduce ruminations (i.e., thinking about negative things repeatedly) and negative mood.[4] One study suggests that brief mindfulness training sessions improve one's emotional state by facilitating an increase in state mindfulness.[5] The efficacy of mindfulness training is, however, influenced by one's individual personality. Those who have higher levels of trait mindfulness may be less anxious, less stressed, and more confident. They may also be more effective self-regulators with better mental-health outcomes than those with relatively low mindfulness traits.[6]

Both *trait* and *state* mindfulness can be measured via self-reported

Abbreviations: VR, virtual reality; MBI, mindfulness based intervention; RCT, randomised control trail.

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questionnaires and other psycho-physiological approaches.[7,8] The most commonly used self-report questionnaires for trait mindfulness are the Five-Facet Mindfulness Questionnaire (FFMQ) and the Mindful Attention Awareness Scale (MAAS). The FFMQ examines five aspects of mindfulness regards one's long-term personality, as follows: non-reaction to inner experience, observation of sensations, acting with awareness, describing with words, and non-judgement of experiences.[9] While the MAAS was constructed based on two components of consciousness – i.e., awareness and attention – the FFMQ mainly concerns one's feelings regarding happiness and well-being.[10] Nevertheless, the MAAS and the FFMQ share some similarities on their structures - the MAAS was also one of the scales from which the FFMQ was constructed.[11] Notably, however, certain measurements were formulated to correlate with specific mindfulness-based interventions.

Mindfulness-based interventions, or MBI, are designed to address particular mental issues, and they may be implemented alongside other clinical treatments.[12] At least one meta-analysis found MBI to be effective in alleviating depression, pain, smoking, and addiction.[13] The most used MBIs are Mindfulness-Based Cognitive Therapy (MBCT)[14] and Mindfulness-Based Stress Reduction (MBSR).[15] The mechanism of MBCT is designed to encourage individuals to evince more self-compassion and self-acceptance.[16] MBSR, conversely, aims to mitigate stress by raising the subject's awareness of the present moment.[15] Both MBCT and MBSR were found to be effective in treating depression and other mental disorders in adult population.[17,18] One meta-analysis confirmed that effectiveness of MBI on treating various mental disorders (*e.g.*, depression, anxiety, *etc.*) and health-related outcomes (*e.g.*, pain, cancer, *etc.*) on different samples.[13] Moreover, the included RCT studies in that meta-analysis has shown heterogeneous effect sizes with regards to types of control groups – studies which adopted inactive control presented larger effect size (*i.e.*, moderate effect size) than studies used active control group (*i.e.*, small, and non-significant effect size).[13] It is indicated that MBIs are effectiveness in most of time, especially for preventing smoking and depression relapse, however, its effects may be undetectable when other treatments are delivered.[13]

By contrast, another study argued that, even though MBCT worked effectively to reduce stress, it was not as successful as hypotheses suggested in relieving anxiety, depression, and distress, or in improving life quality for healthy individuals.[19] Further potential explanations for the practice of dropping out *per se* have not been properly interrogated. Thus, if one aims to explore the efficacy of MBCT, this should be done alongside a consideration of significant or ambiguous variables within the populace, including demography and personality. As regards MBSR, it can prevent relapse into chronic depression when combined with cognitive therapy, and it may reduce social anxiety.[15,20]

To decrease the dropout rates around mindfulness-based treatment, 'Mindfulness in Motion' (MIM) was introduced. This combines mindfulness with music and yoga, and it seems effectively to improve sleep quality and daytime dysfunction.[21] Nonetheless, this has not been found to enhance the work engagement of health staff in a non-clinical environment. Overall, in fact, mindfulness-based interventions may not have the same positive impacts on individuals who evince different demands. Traditional MBI usually requires eight weeks to be spent under the guidance of professional trainers. This is demanding, and many individuals find it challenging to commit to such levels of attendance.

In recent years, a combination of mindfulness and/or meditation training with virtual reality (VR) has been promoted. This model generally comprises specific professional guidance alongside changeable virtual immersive environments, background music, and instant evaluations.[22] Studies have, meanwhile, verified the feasibility of incorporating VR within mindfulness training. One such study found that participants in VR-based mindfulness practice believed their feelings of calmness, relaxation, and peace improved, as did their general emotions and *state* mindfulness.[23] Beautiful scenes, soft music and gentle audio guidance that applied in VR may help users to focus their attention on the practise. This suggests that VR-based mindfulness practice may help individuals maintain present-moment awareness and block distractors and may be more effective than conventional mindfulness approaches. There are limitations, however, including sub-optimal video quality and the heaviness of VR headsets.[22]

The use of digital media in psychological treatment for individuals with mental disorders has been used since the beginning of the 21st century. It has been deployed, for example, to mitigate anxiety, fear of flying, and other specific phobias.[24–26] VR enables the user to generate vivid environments, which can also be manipulated in line with requirements. Most importantly, a sense of 'being there' is provided through VR. The requirement for using a laboratory, or other resource-intensive environments, is thus elided.[25,27] One review addressed that though VR-based treatments may induce motion sickness and dry eyes, they are promising to be employed for specific symptoms of psychiatric disorders as it easily delivered.[28]

Echoing traditional mindfulness training, immersive VR provides aesthetic environments, allowing users to be virtually present in a personalised setting. Moreover, audio guidance replaces the trainer's role, as traditionally evinced in mindfulness training, and this ensures consistency in training quality. The interaction between environment and training, therefore, enhances participants' feeling of involvement and the efficacy of meditation.[29] More recently, a systematic review examined the effectiveness of VR-based mindfulness on psychological and physiological health.[30] The review primarily focused on health aspects, notably the putative improvement of physiological outcomes and certain mental-health areas (i.e., mood, anxiety, etc.). It did not specifically address the enhancement of mindfulness *per se,* however. Like many other studies around VR-based mindfulness practice, which have aimed to improve various health outcomes or to improve the efficacy of other psychological interventions.[31,32] The RCT study which conducted by Navarro-Haro and her colleagues found that the practice of meditation could assist VR-based psychological intervention better in reducing one's anxiety symptoms.

The present review, however, adopts a different approach. Specifically, it aims clearly and simply to summarise the evidence regarding the differences in effect between less immersive (*i.e.*, 2-dimentional computer generated screen), VR-based mindfulness or conventional MBI (on the one hand), and more immersive (*i.e.*, 3-dimentional head mounted VR screen) VR-based mindfulness. The principal objective here is to determine how immersion, in a VR context, can support mindfulness training, thereby generating increased mindfulness levels. No recent Cochrane reviews and systematic review in PROSPERO as well as other databases have been published to address the efficacy of using VR in mindfulness practice. In fact, the current paper is the first systematic review to explore how, and how effectively, VR may facilitate mindfulness training.

The present systematic review attempts to synthesise the pertinent evidence with a view to addressing the following questions:

a) Is mindfulness training, with more-immersive VR, more effective than either less-immersive VR or conventional mindfulness training, with respect to improvements in levels of mindfulness?
b) Apart from mindfulness, what other mental-health-related outcomes have been found to be effectively improved during VR-based mindfulness training?
c) When assisting individuals in practising meditation and mindfulness, what designed VR elements and scenarios are involved?

Materials and methods

This systematic review has been registered in the PROSPERO systematic review database (ID: CRD42021253945).

Inclusion and exclusion criteria

This systematic review explicitly focused on experimental research,

such as randomised controlled trials and single-subject crossover designs. The key interest of the systematic review was to identify studies that were comparison-based (i.e., have two conditions). Thus, studies of interest must demonstrate a comparison of the effectiveness of either (1) VR-based versus non-VR mindfulness or (2) more immersive three-dimensional VR versus less immersive two-dimensional VR training.

According to the principle of PICOS, which was developed by Cochrane Handbook for Systematic Reviews of Interventions (Higgins and Green, 2008), details of inclusion and exclusion criteria are displayed below.

Population

Adults from both clinical and non-clinical populations who seek to improve their mental health outcomes and to train their mindfulness levels using mindfulness-based intervention/training.

Intervention

This review included any mindfulness-based training involving VR. The VR-based mindfulness/meditation training must involve either 2-dimension or 3-dimension virtual reality techniques to provide participants with an immersive experience for mindfulness/meditation practice. The VR-based mindfulness training can be offered to the participants via (1) 3-dimensional VR equipment which contains a visual and audio environment viewed through a head-mounted display, or (2) 2-dimensional equipment (e.g., computer-generated environment).

Conditions

Participants in a control group/condition should not have been offered VR-based mindfulness training; they may only receive audio guidance/offline conventional mindfulness treatment or have remained on a waiting list. If studies compared the conditions of 3D-VR and 2D-VR, the control group condition in this scenario would receive VR training, which would be accepted. Pre and post outcomes will be compared between the VR-assisted group and non-VR assisted/waiting list group(s).

Outcomes

Studies must assess changes in mindfulness level and/or mental health-related outcomes (e.g., mood, well-being, affect, sleep, rumination, etc.) from baseline to the last available follow-up. For example, measures could include the Mindful Attention Awareness Scale, Five Facets Mindfulness Questionnaire, Cognitive and Affective Mindfulness Scale, Positive Affect and Negative Affect Schedule, Pittsburgh Sleep Quality Index: 10-item Ruminative Response Scale, etc.

Selection procedure

Studies were included in the current review if they were published during or after 2016 because there is one similar systematic review published in 2016.[26] That review investigated the use of VR in psychological treatment for mental health problems and included 24 studies. The key search terms in that study covered studies which employed any kinds of psychological treatment (i.e., Mindfulness-based interventions), and there was no MBIs involved in Valmaggia's systematic review. To avoid duplication of systematic review, we therefore believe it was reasonable to search empirical studies that have been published after 2016. Included studies must be written in English, contained original empirical findings, published in a peer-reviewed academic journal, and explored the effectiveness of VR-based mindfulness trainings or meditation practices. Studies were excluded from the review if they were case studies, qualitative studies, single-subject designs without control groups/conditions, not written in English, or review articles/book chapters.

Search strategy

First, the researcher searched the similar review in PROSPERO protocols and the Cochrane Databases to ensure the originality of the present review. Studies for the current review were identified using the following keywords, which were subsequently expanded on using the Boolean operator commands "AND" and "OR": virtual reality OR head-mounted VR AND mindful* OR meditation OR rumination AND adult NOT Child* NOT adolescence NOT cross-sectional NOT survey NOT qualitative NOT interview AND experiment* OR randomised OR randomized control*. These were entered into five databases: Applied Social Sciences Index & Abstracts (ASSIA), PsycINFO, MEDLINE, EMBASE, and Web of Science Core Collection. The literature search has been done by March of 2022.

Citations retrieved were downloaded, duplicates were removed, titles and abstracts were independently screened for eligibility by the first author and correspondence author (JM and JY). Two second authors (DZ and NX) independently assessed the article for eligibility check.

Data extraction

The articles with title and abstracts were managed in Rayyan, which is an online systematic review tool,[33] data extraction of included studies was independently completed by the first and correspondence authors (JM and JY), second authors checked for inconsistency within the extracted content (DZ and NX). To ensure reliability, the final version was agreed on by all four authors, following discussion around any ambiguity. The following items were extracted for all studies as they were pertinent to the review questions: characteristics of the sample, sample size, intervention and control conditions, number of sessions, measurements, scenes displayed in VR meditation, as well as main findings and limitations.

Quality assessment

The quality of studies meeting the inclusion criteria was assessed. The quality rating criteria for the purpose of this research were advised to ensure the studies were applicable to answer the research question. More specifically, the criteria focused on the research design, recruitment and sampling, outcome measures, data analysis, and follow-up measures, which can help with answering the review questions. The existing criteria and guidelines were adapted and designed based on the SIGN 50 Checklist.[34] These criteria of quality assessment tool have been consolidated by Centre for Reviews and Dissemination[35] and adopted by one previous high-standard systematic review.[36] The rating of each quality criterion was classified as well-covered (3 points – evaluation categories clearly reported and can be identified); adequately addressed (2 points – detailed descriptions missing but can be identified from the information); poorly addressed (1 point – no relevant or limited information provided); and not addressed (0 points). Given that each quality criterion is weighted differently according to the overall impact on the quality of the paper, the summed numerical scores were not used as a final rating to avoid misleading quality conclusions. The ratings were finally stated as "++", "+", or "-" to represent high quality, medium quality, and relatively low quality, respectively based on whether the overall rating ranged above 75% (18–24), above 50% (12–17), or below 50% (0–12) of the highest possible rating.

Results

Included studies

2523 studies were identified during the initial search phase. 2398 studies were excluded during the initial title and abstract screen. The full

texts of 106 studies were screened for further eligibility, and only seven of the published studies were eligible to include in this systematic review, [32,37–42] (Fig. 1).

Quality assessment

Two authors reached a 72.5% agreement on quality ratings. Discrepancies were discussed and papers re-appraised until a final rating was agreed by all the authors. Three studies were rated as high quality ("++"), and four studies were rated as medium quality ("+"). Specifically, all the included studies received low scores in the category of follow-up measures (n = 7), it because the included studies did not provide follow-up results. Furthermore, on a positive note, most studies used appropriate, reliable, and valid measurements to measure mindfulness and mental health-related outcomes (n = 6) and most of them employed suitable statistical analysis (n = 6). Overall, the quality of the included studies is acceptable (see in Table 1).

Characteristics of the included studies

The key characteristics of included studies are outlined in Table 2.

Study design

Amongst the seven included studies, five were randomised controlled trials (RCT), with two of them being rated as high quality ("++"),[32,37,40] while the other two were rated as good quality ("+").[41,42] Two studies (both rated medium ("+") quality) used observational repeated measures, including a within-subject design.[38,39] These compared the changes of mindfulness-related outcomes over time within the same group of participants.

Participant characteristics

More than half studies included populations presenting with mental health needs (n = 4), while three studies recruited participants from the general population. The mean age of participants ranged from 17 to 66 years old. These seven studies were conducted across different nations, including Canada (n = 3), Spain (n = 2), Australia (n = 1) and South Korea (n = 1), and included 798 adult participants overall, and 47.74% of them were female.

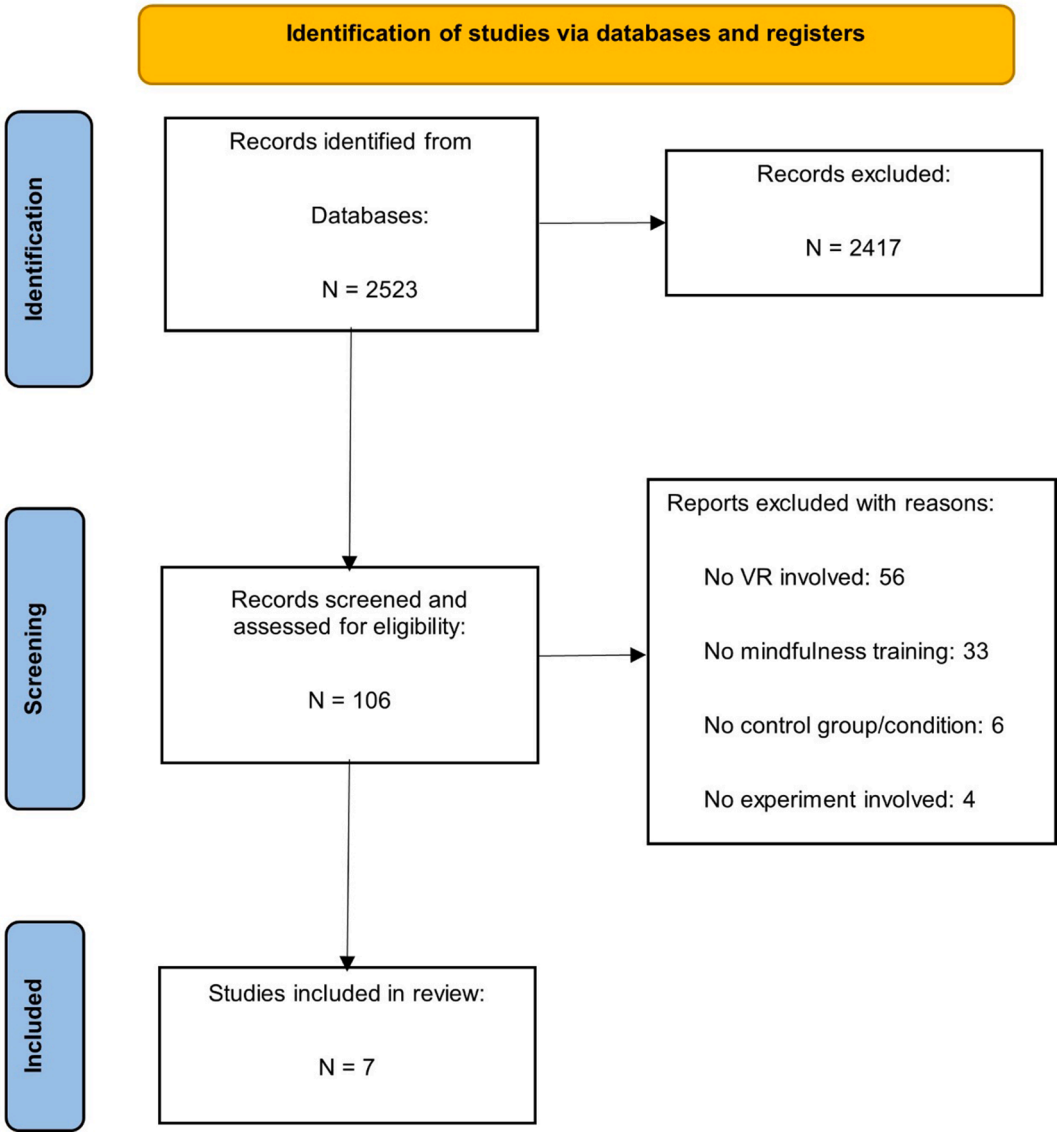

Fig. 1. Flow chart.

Table 1
Quality assessment of included studies.

	Study	Study design	Allocation process	Groups similar at baseline	Addressing the missing data	Recruitment and sampling	Valid and reliable measurement	Follow-up measure	Appropriate analysis	Total score	Overall rating
1	Lee and Kang (2020)	3	3	3	1	3	2	0	3	18	++
2	Waller et al. (2021)	2	2	2	2	2	3	0	3	16	+
3	Mistry et al. (2020)	2	2	1	2	3	3	0	3	16	+
4	Chandrasiri et al. (2019)	3	3	2	3	3	3	0	3	20	++
5	Beshai et al. (2020)	3	2	3	1	2	3	0	3	17	+
6	Barry et al. (2020)	3	2	3	1	2	3	0	3	17	+
7	Navarro-Haro et al. (2019)	3	2	3	3	3	3	0	2	19	++

Intervention

Five of the seven included studies involved 3D head-mounted VR with 360° videos to guide the mindfulness practice. Two employed 2D-VR, which included audio guidance and visual images, accompanied by relaxation music to guide the meditation.[41,42] A limitation of the included studies is that five of them provided only a single session of mindfulness training ranging from five to thirty minutes; only two studies provided multiple and consistent mindfulness practice sessions with VR – four consecutive week trainings and six sessions of trainings, respectively.[32,41] Five included studies reported the scenes displayed in VR during the meditation practice, which were all natural environments, such as landscapes, mountains, seas, trees, boulders, river, mountains, and forests,[38–41] with two of them being rated as high quality ("++").[32,37,40]

Outcome measures and effect size of VR-based mindfulness training

Overall, the outcomes of participants' mood, anxiety, sleep quality, mindfulness level, cognitive function, and experience of meditation were measured using standardised questionnaires and objective measurement. More details about measurements and all citations that applied in the included studies are noted in Table 2. Notably, two included studies did not measure changes in mindfulness and meditation experience before and after the VR-based mindfulness training; only participants' sleep quality[37] and mood and cognitive function were examined.[42]

For the measurements regarding anxiety, the included studies reported significant before-after improvement with large effect sizes, $\eta p2 = .28$,[41] d = - 1.33,[32], and significant interaction effect on time and group ($\eta p2 = .04$), and on group ($\eta p2 = .03$), with small effect size, indicating that both conventional and VR-based mindfulness training improve anxiety outcome after the intervention, and the VR-based mindfulness training exhibited greater effectiveness on anxiety than the control group.[41]

For the measurement of stress level, the significant interaction effect between group and time with medium effect size ($\eta p2 = .09$), significant between group effect with small effect size ($\eta p2 = .04$), and significant effect on time with large effect size ($\eta p2 = .49$) have been reported. It has shown that trainings on both group (VR-based mindfulness training versus conventional mindfulness training) effectively decreased participants' stress, and the participants in VR-based mindfulness group reported less stressful than those in control group.[41] For depression, one included study reported significant before and after reduction on depression for VR-based mindfulness training group (b = -.54) with medium effect size, indicating that VR-based MBI can reduce depression symptoms after multiple sessions.[32]

With regards to the measurement of emotion, four included studies employed several instruments measured mood, emotion-regulation, and positive affect. Positive affect was found significantly improved after mindfulness trainings for both VR-condition and conventional condition with large effect size ($\eta p2 = .40$), and significant between-condition differences on positive affect were found with large effect size ($\eta p2 = .27$), implying that VR-based mindfulness training yielded greater effectiveness on audio-instructed mindfulness training.[39] Furthermore, with the same measurement, positive affect was found improved, and negative affect was found decreased, between VR and non-VR meditation with large effect size ($\eta p2 = .30$; $\eta p2 = .23$), indicating that VR-based meditation can improve positive affect and decrease negative affect greater than non-VR meditation condition.[38] Another study measuring mood that indicated significantly greater positive mood enhancement in visual meditation group than audio group and control group with large (d = .82, 95% CI [2.18, 7.15]) and medium effect size (d = .60, 95% CI [.76, 5.92]), respectively.[42] Additionally, the changes of emotion-regulation have been reported to be significantly increased after the VR-based MBI in terms of subscales of confusion (d = .59), interference (d = -.84), and impulse (d = -.89) with medium and large effect sizes.[32]

Notably, five included studies measuring mindfulness and mediation degree employed different instruments (reported in Table 2). For the trait mindfulness measured by FFMQ, it has been found that both intervention groups exhibited significant improvement on overall mindfulness with large effect size ($\eta p2 = .28$,[41]; d = -.84,[32]), and significant interaction effect on group and time with small effect size ($\eta p2 = .03$).[41] For the state mindfulness, medium interaction effect on group and time was identified ($\eta p2 = .07$), meaning that VR-based mindfulness group significantly improved participants' state mindfulness than control group.[41] By contrast, improvement on decentering (subscale of state mindfulness) after the mindfulness training in VR group was significantly greater than the control group with large effect size (d = .96).[40] Regarding meditative experience, it was reported that small significant interaction effect size between intervention type (VR versus conventional meditation) and time (pre and post intervention) on meditative attention ($\eta p2 = .05$), whereas large effect size on interaction effect on intervention type and time was identified ($\eta p2 = .28$) on meditative experience.[38]

For measurement of sleep quality, significant between-group effect has been found with large effect size (d = .95), and the participants who received VR-based mindfulness training reported greater overall sleep quality than control group[37]. Additionally, attention and cognitive function were measured by Trail Making Test parts. With medium effect size (d = -.55), between group differences on executive functioning was found significantly, and VR-meditation group reported quicker time reaction on cognitive tasks compared with participants in control

Table 2
Key characteristics of included studies.

Author Year Country	Clinical Sample	Mean age N	Design	Treatment Control Interventions (or conditions)	Scenes displayed during the VR meditation	No. of Sessions Outcome Measurements	Main Findings	Strengths Limitations
Beshai et al. 2020. Canada		44.1.		2D self-guided mindfulness intervention - Mind-OP		4-week of one *per* week.	4 Anxiety and stress.	Large sample
	General population	N = 456	RCT	Watching video with nature images along with relaxing meditation music.	Not specified.	GAD-7; PHQ-9; PSS; FFMQ-15; SCS-SF; NAS- SF; TMS.	t Mindfulness, self-compassion, And nonattachment.	size. No follow-up.
Lee and Kang 2020. South Korea	Admitted to the ICU with cardiovascular disease.	66.42.		Head-mounted VR equipment + relaxing music + meditation video	Natural images and 360°	Single session - 30 min		Large sample size. No measurements for mindfulness; Single training session.
		N = 48	RCT	Daily routine sleep protocol without mindfulness practice. 3D head-wear VR + Video guided meditation	landscape (i.e., sea, mountain, lakes, etc.)	PSQI; 'Korean Sleep Scale A'; Activity tracker FitBit Charge 2.	t Sleep quality	
Mistry et al. 2020. Canada	University students (general population)	24.02. N = 96	Crossover-within-subject	Non-VR meditation practices - either view 2D screen with meditation instruction or eyes-closed only listening audio instruction.	Natural views - tropical rainforest; a hidden cave; an island; Underwater coral reef; foreign planet.	Single session - 5 minutes. Modified Differential Emotions Scale (mDES); BASS; MEQ; SCQ	t Positive affect, satisfaction credibility.	Large sample size. Non RCT; Single time training. High attendance.
Barry et al. 2020. Spain	Diagnosed with schizophrenia	38.1. N = 43	RCT	2D VR meditation practice. Conventional meditation with auditory guidance.	Colours, mandalas, and landscapes (e.g., mountain stream).	Single session -30 min Spanish PANAS; TMT	t Positive mood. t Attention and cognition.	No follow-up; single-time training; no standardized measurement of mindfulness.
Chandrasiri et al. 2019. Australia	History of Psychiatric or neurological disorder	27.25 N = 32	RCT	3D head-mounted display VR. Audio track mindfulness instruction with eyes closed.	Walk on the beach' relaxation video.	Single session -45 min. The Toronto Mindfulness Scale (TMS) - Curiosity and decentring.	t Level of decentring.	High attendance. No follow-up; singe time training
Waller et al. 2021. Canada	General population	Mean age not stated; Age range 17-28.	Counter-balanced design	360° guided meditation by using a VR HMD Either in-person guided meditation or 2D laptop displayed	Not specified. But the video is audio-led instructions for meditation.	Single session - 5 minutes. SCQ; mDES; BASS; MEQ; MBAS.	t Positive emotion. 4 Negative affect. t Meditation.	Large sample size, and various measurements Single session and within-group design.

(*continued on next page*)

Table 2 (*continued*)

Author Year Country	Clinical Sample	Mean age N	Design	Treatment Control Interventions (or conditions)	Scenes displayed during the VR meditation	No. of Sessions Outcome Measurements	Main Findings	Strengths Limitations
		N = 82		mindfulness practices			4 Anxiety and	
				MBI	Sceneries of trees, boulders, river, and	Six sessions with 100 min (MBI 90min + 10min VR) training per week.	depression. t Trait mindfulness and	Multiple training sessions.
Navarro-	Diagnosed by			MBI + VR (3D	mountains		awareness.	Small sample size; VR-session were short (10 min); no follow-
Haro et al. 2019 Spain	General Anxiety Disorder	45.23 N = 39	RCT	head-mounted displayed) Dialectical Behaviour Therapy	displayed along with audio guidance to train Mindfulness skills.	FFMQ; GAD-7; HADS; DERS; VAS.	t Emotion regulation. t Adherence to intervention attendance.	up.

Note. The questionnaires that the included studies shown in the table include Generalized Anxiety Disorder – 7 (GAD-7; Spitzer et al., 2006), the Patient Health Questionnaire – 9 (PHQ-9; Spitzer et al., 2000), The Self-Compassion Scale – Short Form (SCS-SF, Raes et al., 2011), the Nonattachment Scale – Short Form (NAS-SF; Chio et al., 2018), Korean Sleep Scale A (Oh et al., 1998), the Perceived Stress Scale (PSS; Cohen et al., 1994), the Meditative Experiences Questionnaire (MEQ; Mistry et al., 2020), Satisfaction and Credibility Questionnaire (SCQ, Mistry et al., 2020), Trail Making Test (TMT, Arnett, and Labovitz, 1995), the Toronto Mindfulness Scale (TMS, Lau et al., 2006), the Five Facet Mindfulness Questionnaire -15 (FFMQ-15, Gu et al., 2016), the Modified Differential Emotions Scale (mDES, Keltner, and Shiota, 2003), Buddhist Affective States Scale (BASS; Mistry et al., 2020), Spanish Positive and Negative Affect Schedule (PANAS, Ortuño-Sierra et al., 2015); Meditation Breath Attention Scores (MBAS, Frewen et al., 2016), Pittsburgh Sleep Quality Index (PSQI, Buysse et al., 1989), Hospital Anxiety and Depression Scale (HADS, Terol et al., 2007), Difficulties of Emotion Regulation Scale (DERS, Hervás and Jódar, 2008), and Visual Analogy Scale – emotional state (Gross and Levenson, 1995).

group.[42]

Summary of findings

This review identified five randomised controlled studies and two counter-balanced design studies published since 2016. Overall, this review suggests that VR-based mindfulness training facilitated improved levels of trait and state mindfulness with small to large effect size.[32,38,40,41] For included studies which employed RCT design, it is indicated that both VR and non-VR mindfulness groups yielded significant improvement on trait mindfulness after the intervention with large effect size.[32,41] Nonetheless, VR-based mindfulness training has shown more effective than non-VR mindfulness in terms of cultivating both trait and state mindfulness levels with small effect size.[41] For another RCT that included in the review, decentering levels of mindfulness were more significantly improved in VR group than non-VR control group with large effect size.[40] Other two cross-over designed studies have shown that participants reported higher levels of meditative attention and experience when they received VR-based meditation than they received non-VR audio or control (i.e., just close the eye) meditation practice. In summary, the included experimental studies in the present review have shown better experience of mediation and greater levels of mindfulness state/trait using VR-based mindfulness training than non-VR training.

Specifically, more immersive VR-based meditation practices or mindfulness trainings are more likely to provide extra benefits such as a more positive mood, better sleep, reduced stress and anxiety, emotion regulation, and cognitive attention than less immersive or non-VR meditation.[32,37–39,41] For example, this review concluded that VR-based mindfulness training can be more effective to reduce stress and anxiety in adults than control groups with small effect size.[41] For mood and emotion, two within-subjective (counter-balanced) designed study reported that positive mood and emotion improved more significantly in VR group than the control with large effect size,[38,39] whereas another RCT study found the similar results with medium to large effect size.[42] Therefore, VR-based mindfulness training can effectively improve positive mood and reduce negative mood than conventional mindfulness trainings. Additionally, two RCT studies in the review found that VR-based mindfulness training enabled to improve adults' sleep quality and cognitive attention.[37,42]

To sum up, except the outcomes related to mindfulness level and experience, VR-based mindfulness training has been found to be effective on improving mood, emotion-regulation, and attention. Furthermore, it showed that most VR-assisted mindfulness trainings involve natural environmentally related elements, such as forest, grassland, caves, and sea, etc. Because VR-assisted meditation consistently utilises video is under-researched, it remains unclear as to how nature-related videos benefit meditation.

There are limitations to the methodologies followed in these studies. None of them have measured levels with a follow-up, except two studies with 4-week and six times constant mindfulness trainings.[32,41] The remaining studies included implemented just one training session, which makes the training successful, or otherwise susceptible to confounding variables. Furthermore, two studies did not employ any standardised measurements to examine mindfulness and meditation-related outcomes.[37,42] It is, accordingly, a very difficult process to identify whether VR-based mindfulness training had any influence on the changes noted in mindfulness, as seen in the results. Though Lee and Kang[37] investigate the effects of VR-based meditation on sleep quality, the findings can be considered more comprehensive because the study explored the mediating role of mindfulness in the relationship between the training and sleep quality, or vice versa. Consequently, it remains unclear about how cognitive function, such as attention, might be improved through a VR-based mindfulness training session, as well as its role in mood. Further research in this area could also explore the impact of VR-based mindfulness training on sleep, mood, the feeling of connectedness to nature, and attention.

Discussion

The current study aimed to evaluate the effectiveness of VR-based mindfulness training through systematically reviewing the published literature. Seven empirical studies have been searched, including five RCTs and two cross-over within-subjective designed research, which contained 798 adult participants. The magnitude of effectiveness of VR-based mindfulness training enhancement in mindfulness levels and

other mental health outcomes were ranged from small to large. Regarding the quality assessment of the included studies, three of them were rated with relatively good quality, and the rest of them were rated with adequate quality. Therefore, the quality assessment results were similar and have been considered in the conclusion. Notably, the current review is not restricted to RCTs, and the outcome measures vary. The narrative synthesis answered the review questions.

For the first review question, this systematic review suggests that more-immersive VR-based mindfulness training tends to be more effective than either less-immersive VR or conventional mindfulness training in improving mindfulness levels, apart from one study which has not statistically compared two groups' differences on measured outcomes.[32] That study took two separate statistical analysis to investigate the effects of MBI, and MBI + VR on anxiety, depression, and mindfulness, but it is found that VR-based mindfulness trainings presented lower drop-out rate and higher adherence to the intervention compared with conventional mindfulness trainings.[32] These findings are overall consistent with a conference report, which conducted an experiment to compare the efficacy of VR-mindfulness training and audio-guided mindfulness, with participants in a VR mindfulness group showing a significantly greater level of state mindfulness than those who meditated with audio guidance.[43]

For the second review question, it is suggested that apart from mindfulness, positive mood, attention, anxiety, depression, emotion-regulation, stress level, sleep quality as well as cognition have been found to be effectively improved after the VR-based mindfulness training. These findings are consistent with a previous experiment study, which demonstrated that short time mindfulness training can not only effectively benefit meditation practice and mindfulness level, but also effectively improve adult participants' executive attention, psychological well-being, and decrease their anxiety and depression.[44] Furthermore, another recent empirical study, which evaluated the effectiveness of an online mindfulness-based stress reduction program amongst adult population, has found the significant effect of the intervention on reducing anxiety and stress and increasing emotion regulation.[45] The current review confirmed that VR-based mindfulness training can be also effective on improving mental health outcomes and yielding additional benefits on anxiety, mood, stress, and executive attention, etc.

For the final review question, the present review found that natural environments were presented in VR screens to assist meditation/mindfulness practice. According to the Attention Restoration Theory developed by Kaplan and Kaplan, nature environments reduce mental fatigue and increase one's attention, as visual stimuli of nature boost effortless attention.[46] An experiment from one study suggested that nature can boost one's ecological behaviour, regardless of whether this was through real or virtual nature.[47] By contrast, another randomised control study found that participants in experimental (exposure in real nature) and control groups (exposure in VR nature) perceived greater levels of nature connectedness belief compared with a baseline measured by Nature Related Scale, but no group difference was identified by using the State of Independence Scale. This indicates that both approaches of incorporating nature are useful.[48] Although the conclusions of these two studies differ slightly, on account of different data sets and methods used, the findings essentially indicate that the natural environment can play a role in meditation effectiveness through VR. It demonstrates that meditation practice can strengthen attention restoration from VR-based nature exposure.[49] In turn, stronger perceptions of being in nature via VR are significantly correlated with more in-depth meditation experiences.[50] Further studies are desirable to investigate the possible moderating/mediating role of the degree of nature connectedness in relationship to the improvement of mindfulness and the application of VR-based mindfulness practice.

Limitations and implications

This systematic review has several limitations. First, due to heterogeneous measurements and methods of the included studies, it was not possible to carry out a meta-analysis to identify the exact effect size of the VR-based mindfulness training. Secondly, this review focuses on adults, both in general and clinically, and accordingly does not address the effect or application of VR-based mindfulness on children and young people's mental health and education. Thirdly, only a limited number of studies (n = 7) were included in this study, and so this restricts the robustness of the conclusions we can draw with regards to the effectiveness of VR-based mindfulness training. Moreover, due to the restricted number of studies conducted to compare efficacy of VR-based mindfulness training and conventional mindfulness intervention, this systematic review included two different control comparisons – conventional mindfulness training and non-active control (i.e., no mindfulness training involved). Different control interventions may yield bias. For instance, two studies[37,41] did not involve mindfulness training for their control groups. Therefore, even they found VR-based mindfulness meditation had greater effect on participants' sleep improvement and anxiety reduction, the effect may be brought by mindfulness itself, rather than assistance of VR. Thus, the conclusion that we may draw as safely and concisely as possible is that VR environment may replace conventional MBI trainer in delivering trainings, Nonetheless, these two studies are included and evaluated because they showed the feasibility and effectiveness of VR-based mindfulness trainings.

Finally, each of all the included studies had only short-time session (s) of mindfulness training. Few of these studies indicated how VR-based training differs from, or makes no difference with, the conventional MBI. As a result, the researchers of these studies were only able to detect instant effect of improvement of mindfulness or other mental health outcomes. Whether these effects remained after the training is unknown from these studies.

For further studies which attempt to compare the effectiveness of conventional MBI and VR-based MBI, researchers should, firstly, involve well-formed convention MBI and include self-helped VR-based MBI for eight-weeks, in order to find out participants' experience of both two mindfulness trainings and whether VR assisted mindfulness training make it easier for them to maintain the engagement; secondly, they should compare changes of both state and trait mindfulness for two groups of participants after eight-week training. In that way, we may determine (a) whether VR-based MBI helps to elevate the level of mindfulness, (b) the best dose of VR-based MBI, and (c) in which aspect (i.e., state or trait) VR-based MBI is more effective in mindfulness improvement than conventional MBI, or vice versa.

Nonetheless, these findings of the present systematic review improve our understanding of the efficacy and application of mindfulness/meditation training facilitated by VR. As with all mindfulness training, it requires people to be aware of their surroundings and completely focus their attention to succeed. VR can help reduce distractions that prevent this focus while also being able to present vivid restorative natural imagery that can further increase the feeling of calmness and positivity required. Empirical studies that compare the effects of VR-based mindfulness training with various formats (e.g., different meditation apps, virtual environments, background music, and auditory guidance) are also required to enhance our understanding of this field.

Conclusion

This review synthesised evidence of the effectiveness of VR-based mindfulness training in adults, providing evidence that practicing the VR technique impacts the level of state/trait mindfulness, mood positivity, emotion regulation, and benefits to sleep quality. Questions remain, however, about the most effective dose (i.e., length of the training), the most effective components of VR display, and potential mediators and moderators that may impact the effectiveness of the training. Further randomised controlled studies are required to compare the effectiveness of distinct levels of engagement in immersive VR mindfulness training in the improvement of mindfulness/meditation,

mood positivity, sleep quality, and anxiety; and to examine the content of display videos that may best assist with the efficacy of meditation training.

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