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Mindful of the Virtual Experience: Virtual Reality Technology Specifications, User Experience, and Outcome

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Virtual reality (VR) is increasingly being incorporated in mental health interventions, although little is known about users' experiences with these different types of technology. This study aimed to examine potential differences in user experiences across three different fully immersive VR head-mounted displays (low, medium, and high range) that varied in cost, technical specifications, and quality. A one-session, mindfulness-based VR intervention was utilized. It was predicted that a more positive user experience would be observed for the high-range than low-range condition and that mindfulness and affect would increase postintervention. Participants were 75 university students aged 18 years and older, who were randomly allocated to one of the three VR groups: low-range (i.e., VR Shinecon), medium-range (i.e., BOBOVR Z6), or high-range (i.e., Oculus Quest 2). Each participant completed a 20-min mindfulness-based VR intervention and completed qualitative questions and outcome measures of presence, cybersickness, satisfaction, mindfulness, and affect. A series of mixed factorial, one-way analyses of variances were conducted on quantitative data. Inductive and deductive content analysis was performed on qualitative data. Results revealed that greater presence was reported among participants in the high-range head-mounted display group than the low-range group. Additionally, mindfulness scores improved pre- to postintervention irrespective of the type of head-mounted display used. Mindfulness and participant satisfaction did not significantly differ between conditions. Participants in the high-range condition reported a more positive user experience and had fewer concerns about technological factors. Overall, the study highlights the importance of considering user experiences when selecting VR interventions and technology. This study addresses a gap in the understanding of user experiences across VR technology quality and contributes to translation and adoption efforts for VR interventions when selecting VR technology for practice.

Public Significance Statement
Users can benefit from a mindfulness-based virtual reality (VR) session, irrespective of headset quality or cost. However, users who prefer a more immersive experience would benefit from higher quality VR technology. Lower quality VR technology is a suitable and affordable alternative. These insights help to make more informed decisions regarding the selection of VR technology for practicing mindfulness.

Keywords: virtual reality, digital mental health, mindfulness, technology

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Mental health systems face substantial challenges with the growing rate of mental health disparities outpacing the provision of timely, affordable, and evidence-based mental health services (Clough et al., 2022; Ganapathy et al., 2024; Prescott et al., 2022). Barriers to care (e.g., limited-service access, delays in service provision, limited resourcing, increased costs, workforce shortages) result in unmet mental health needs for many individuals (Prescott et al., 2022), highlighting an urgent need for more effective implementation and translation efforts to address the mental health crisis (Chung et al., 2022; D. P. Rowland et al., 2022). Virtual reality (VR) technology is an innovative approach to addressing unmet mental health needs; however, technological advancement has often outpaced research trials, which in turn has slowed translation and implementation efforts (Ganapathy et al., 2024; Kouijzer et al., 2023). While evidence supporting the effectiveness of virtual reality interventions (VRIs) continues to grow, the adoption and long-term integration of these technologies remain hindered by contextual factors such as the role of user experiences on outcomes (Fares et al., 2024). Addressing these factors is crucial for developing knowledge translation resources that can facilitate the smooth integration of VR technologies into mental health care, ensuring these innovations are both effective and user-friendly in real-world settings.

Virtual Reality Technology

VR technologies produce sensory stimuli that create a realistic, interactive, and immersive experience of three-dimensional environments to allow users to experience the feeling of being present in a different physical space (Rizzo et al., 2019; Sanchez-Vives & Slater, 2005). Typically, the computer-generated virtual environment (VE) is observed through dual-display stereoscopic technology, such as through head-mounted displays (HMDs), which is commonly known as immersive VR, whereas semi-immersive VR utilizes projection screens, and nonimmersive VR is typically delivered via traditional two-dimensional screens (Bowman & McMahan, 2007). These are worn on the head with some technologies having specifications for tracking body and eye movements (Howard, 2019). HMDs send slightly different images to each eye, which generates illusory depth (Riva, 2003). Such technology creates illusions of movement, distance, location, and speed (Clough & Casey, 2011). Some HMDs allow for multisensory input; for instance, they can be equipped with inbuilt or separate headphones to generate stereophonic sound (Riva, 2003). Users can purchase a variety of HMDs based on preference, cost, technical specifications, portability, and comfortability. HMDs can range from high-quality products, such as the Oculus Quest 2 and HTC Vive, to lower quality products, such as the Google Cardboard (Yildirim & O'Grady, 2020). Despite the many options for HMDs, few studies in this field adequately report on the role of VR technology factors and how these might influence outcomes, with studies prone to reporting findings from outdated, discontinued, costly, or unavailable VR products (D. P. Rowland et al., 2022). It remains unclear which technology-specific factors are associated with user experiences and outcomes (Geraets et al., 2021; Modrego-Alarcón et al., 2021).

Virtual Reality User Experiences

Theoretical frameworks (e.g., Fares et al., 2024; Kim et al., 2020) regarding the uptake of VR emphasize that the type of VR technology and hardware influences the user experience (Chang et al., 2020, 2024). However, research has primarily focused on user experiences of VR technology in the context of general display features such as presence, immersion, and cybersickness, rather than on specific technology factors such as comfort (e.g., weight and fit) or specific display factors (i.e., field of view, frame rate, optical flow, content; Chang et al., 2020; Kim et al., 2020). Presence is a subjective perception or psychological state of feeling present in a VE (Cipresso et al., 2018), whereas cybersickness refers to the adverse effects and symptoms users experience during or after VR use, such as nausea, disorientation, oculomotor difficulties, eyestrain, blurred vision, and fatigue (Chang et al., 2020; Riva, 2003). Slater and Wilbur (1997) posited that the degree of presence a user experiences depends on the quality and level of immersion delivered by VR content and technology. When immersion, technical, and content quality are high, users have reported more positive emotions, experiences, and higher engagement with VR (Bouchard et al., 2012; Bulu, 2012; Howard, 2019; Ling et al., 2013), and studies have demonstrated that users prefer more immersive HMDs over low-immersive and semi-immersive technology (Chang et al., 2020; Dennison et al., 2016; Kim et al., 2020). Users typically expect a VE to immediately respond to their movements. However, in many VR systems, there is a delay, due to factors like frame rates or processing times, between a participant's input (e.g., head movement) and the system's visual output (Chang et al., 2020). This temporal mismatch, known as vection, can create sensory conflict, potentially resulting in cybersickness. A review by Weech et al. (2019) reports that greater immersion increases presence and cybersickness. This poses a challenge for optimizing the user experience as higher levels of presence result in positive user experiences, whereas cybersickness negatively impacts the user experience (Caserman et al., 2021; Weech et al., 2019). However, evidence also supports that obtaining expensive hardware or building overly intricate VEs to accomplish positive intervention outcomes such as presence may be unnecessary (Kelson et al., 2021).

Intrusive technology factors, such as sensory mismatch, low frame rates (slow speed of images shown), low field of view, low degrees of freedom, vection, prolonged durations of exposure to a VE, low interactivity intuitiveness, and subpar navigational controls, can negatively impact immersion, presence, and user experience (Chang et al., 2020; Saredakis et al., 2020; Weech et al., 2019). A study conducted by Martirosov et al. (2022) examined three levels of immersion in a VE delivered in different VR modalities: computer (low immersion), CAVE (semi-immersive), and Oculus Rift (fully immersive). Their findings supported the conclusions from Weech et al.'s (2019) review, whereby more immersive technology results in greater levels of presence and cybersickness compared to less immersive technology. Putawa and Sugianto (2024) compared modern, fully immersive HMD devices that had similar technical specifications (i.e., HTC Vive, Playstation VR, and Oculus Rift). Participants reported moderate-to-high levels of immersion irrespective of the VR device used, with 45% of the sample preferring to use the Oculus Rift due to greater comfort and less experiences of eyestrain, cybersickness, and fatigue. It remains unclear whether the relationship between user experiences, VR technology quality, and outcome is linear or whether a basic minimum standard is required. To the authors' knowledge, no known studies have sought to make direct comparisons across different HMDs based on technical specifications and quality of VR HMDs and whether this influences the user experience and mental health outcomes in VRIs.

Virtual Reality Interventions and Mindfulness

VRIs apply VR technology to promote psychological and behavioral change to achieve symptom reduction in clinical, subclinical, and nonclinical populations (Turner & Casey, 2014). The capacity to create tailored, stepped, and safe environments through VR has resulted in substantial evidence focusing on the use of this technology for the treatment of various psychopathologies. Several reviews (Botella et al., 2017; Gonçalves et al., 2012; Valmaggia et al., 2016) and meta-analyses (Carl et al., 2019; Fodor et al., 2018) have demonstrated the clinical efficacy of VRIs (Carl et al., 2019; Riva et al., 2019; Valmaggia et al., 2016). However, these have mainly been for the treatment of unidimensional disorders (e.g., anxiety disorders), rather than as a transdiagnostic approach to treatment (D. P. Rowland et al., 2022). Mindfulness-based VRIs have been typically researched in nonclinical populations with few demonstrating efficacy in clinical populations (H. Li et al., 2021; Ma et al., 2023; H. Zhang et al., 2021). Synergy between mindfulness and VR as an intervention provides innovative transdiagnostic solution for addressing unmet mental health needs (S. Zhang et al., 2023). Mindfulness VRIs provide a controlled and immersive environment that simulates real-world stressors for greater rehearsal and application of mindfulness skills across contexts (Ma et al., 2023; Navarro-Haro et al., 2017; S. Zhang et al., 2023).

Mindfulness refers to "the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment" (Kabat-Zinn, 2003, p. 145). Traditional mindfulness therapies and online mindfulness treatments are efficacious for the treatment of various mental health problems (Khoury et al., 2013; Sommers-Spijkerman et al., 2021). A systematic review by S. Zhang et al. (2023) concluded that mindfulness-based VRIs could induce relaxation, presence, and deeper meditation experiences than traditional mindfulness treatments; however, limited studies hindered meta-analytic approaches to determining efficacy.

For example, Yildirim and O'Grady (2020) investigated the efficacy of a brief (10 min) mindfulness-based VRI when compared to an audio-based intervention and control group. The greatest levels of state mindfulness occurred for participants in the VR group (Yildirim & O'Grady, 2020). This finding was consistent with Navarro-Haro et al. (2017) and Seabrook et al. (2020) who concluded that VR can effectively facilitate mindfulness by leveraging presence to isolate participants from distractors, thus increasing present-focused awareness and furthering engagement with mindfulness. There remains a lack of available evidence to support the efficacy of mindfulness-based VRIs, and the role of technological specifications and quality on outcomes remains poorly understood (Ladakis et al., 2024; Ma et al., 2023; H. Zhang et al., 2021). This knowledge gap makes it difficult to ascertain what technological conditions may be necessary to deliver a positive mindfulness experience to VR users.

The Present Study

The present study examined the impact VR quality has on user experiences and outcomes within a mindfulness-based VRI. The study sampled university students due to the high levels of stress and mental health problems in this population (Stallman, 2010). For example, the World Health Organization found 93.7% of university students experienced mild stress symptoms, with 13.4% meeting criteria for major depressive disorder and 13% meeting criteria for generalized anxiety disorder (Karyotaki et al., 2020). These prevalences are significantly higher than those of the general population based on 12-month prevalence estimates reported by the 2019 global burden of disease study (i.e., 3.4% for major depressive disorder and 3.8% for anxiety disorders; Murray, 2022). More recent global prevalence estimates for anxiety and depression in university students have increased to 33.6% and 39%, respectively (W. Li et al., 2022). Mindfulness-based interventions have been suitable to support this population (Hindman et al., 2015; Regehr et al., 2013). This population was also considered to be a likely target group for adoption of VR technology for mental health, as university students are typically more digitally literate and engage in frequent use of technology compared to the general population (Blagojević, 2022; Plechatá et al., 2019).

University students were randomly allocated to engage in a one-session, mindfulness-based VRI using one of three HMDs of varying quality, technical specification, and price. These were the VR Shinecon, BOBOVR Z6, and Oculus Quest 2 as representing low-, medium-, and high-range HMDs, respectively. Delineation between the three HMDs was done based on clear differences in the year of release to users, price, frame rate, resolution, and various technical specifications. To examine possible differences in user experiences between the HMDs, mindfulness, presence, treatment satisfaction, and cybersickness were measured. Additionally, qualitative questions regarding the user experience were administered to better understand outcomes from the intervention and whether participants responded differently based on the type of HMD used. The following hypotheses were grounded in previous research. It was hypothesized that:

1. Participants in the high-range HMD condition would report more positive user experiences than participants in the low-range HMD group, evidenced by qualitative findings and significantly higher scores on presence (Donker et al., 2019; Weech et al., 2019) and treatment satisfaction (Martirosov et al., 2022; Putawa & Sugianto, 2024).

2. The high-range group will report significantly higher scores on cybersickness than the low-range group (Putawa & Sugianto, 2024). Findings on the relationship between technology factors and cybersickness remain inconsistent, with mixed findings within the literature (Weech et al., 2019). More immersive VR technologies are said to increase cybersickness (Chang et al., 2020). However, few studies have compared cybersickness in equally immersive VR HMDs that have different technological specifications.

3. Across all conditions, significant improvement would be reported postintervention compared to preintervention for mindfulness (Blackmore et al., 2024; Chandrasiri et al., 2020; Navarro-Haro et al., 2017), positive affect, and lower negative affect (Blackmore et al., 2024; Seabrook et al., 2020), with the greatest and lowest gains experienced by participants in the high- and low-range HMD groups, respectively, due to the enhanced quality and better technical specifications of the headset.

4. No predictions were made regarding the medium-range HMD group, with potential differences investigated in an exploratory manner. Although more advanced displays should result in better outcomes and user experiences, recent advances in HMDs may create a ceiling effect for this relationship (Howard, 2019). That is, the medium-range HMD may provide the necessary user experience to achieve treatment gains, with the quality of the high-range HMD not providing any significant additional benefits (Clough & Casey, 2011; Kelson et al., 2021; D. P. Rowland et al., 2022).

Method

Minimum sample size was determined using a priori power analysis. Previous literature has supported a large effect size (d = 1.35) between presence when comparing VR to two-dimensional computers (Filter et al., 2020). However, to the authors' knowledge, none have compared different VR HMDs. As such, a large between-group effect was expected, although this estimate was made more conservative than Filter et al.'s (2020) findings to account for greater overall presence expected across VR conditions. Therefore, the minimum sample size was determined to be 75 participants (25 per group), based on an expected large between-group effect size of d = 0.80, $\alpha = .05$, and $\beta = .80$.

Participants

A total of 75 university students aged between 18 and 52 years of age (20 male, 53 female, and two nonbinary) were recruited from a participant pool of students enrolled in an undergraduate university program. The average age of the sample was 24.51 years (SD = 8.82), with individuals aged 18 years being the largest age group ($n = 29$) and consisting of more than a third (38.70%) of the sample. Most participants were White/European Australian (75%). The inclusion criteria required participants to be aged 17 years or older and be enrolled in a program and course of study at a university. All participants recruited to the study met this eligibility criteria. Demographic data were collected to assist in determining the relevance of the data to community populations: age, gender, and ethnicity. Descriptive data on the ethnicity of participants are provided in Table 1.

Study Design

The present study was an extension of a registered randomized control trial (ACTRN12624000305527), which employed a similar study design, and delivered the same intervention and compared different digital mental health modalities (i.e., VR, smartphone, and computer).

Table 1
Descriptive Data for Participants' Ethnicities

Ethnicity	Number (n)	%
White/European Australian	59	78.70
African	3	4.00
Asian	6	8.00
Hispanic	1	1.30
Fijian Indian	1	1.30
Iranian	1	1.30
Pacific Islander	1	1.30
Polynesian	1	1.30
White New Zealander and Indian (biracial)	1	1.30
African and White (biracial)	1	1.30

Note. $N = 75$.

Quantitative Analyses

To investigate user experience variables (presence, cybersickness, and treatment satisfaction), a one-way between-participant design (data from the postintervention time point only), with three levels (low-, medium-, and high-range headsets), was employed. For treatment outcomes (mindfulness and affect), the study employed a mixed 2 (within-participants, pre, and post) × 3 (between-participants, low-, medium-, and high-range headsets) factorial design.

Qualitative Analysis

Inductive (sentiment analysis) and deductive (conceptual analysis) content analyses were conducted on responses to open-ended survey questions using ATLAS.ti Scientific Software Development GmbH (2023). The coding process was developed, piloted, and iteratively refined to ensure consistency and reduce bias. Although a single coder was used, both manual and generative artificial intelligence coding were employed, with artificial intelligence-generated codes cross-checked by the research team against manual coding to ensure accuracy and alignment. For the sentiment analysis, predefined sentiment labels (i.e., positive and negative) aligned with the study's questions regarding likes, dislikes, and recommendations for the VR intervention and technology. This approach quantified the emotional tone of participant experiences and helped inform future improvements (Wilson, 2013). The content analysis followed Fares et al.'s (2024) framework to ensure theoretical grounding, categorizing data into four main themes: "users," "environment," "technology," and the original "construction" theme, which was redefined as "industry" to reflect occupational and service delivery factors (e.g., safety, performance, development, and training). Text analysis (e.g., word frequencies) was performed to identify recurring words and concepts, ensuring consistency between codes, concepts, and themes. Descriptive statistics (i.e., frequencies and percentages) were used to quantify sentiments and commonly occurring concepts. Additionally, a chi-square analysis was conducted to examine the relationships between HMD conditions and sentiments.

Materials and Measures

Mindfulness

The Toronto Mindfulness Scale (TMS) by Lau et al. (2006) is a 13-item questionnaire measuring mindfulness as an emotional state of curious, decentered awareness. It uses a 5-point rating scale ranging from 0 (*not at all*) to 4 (*very much*). Items such as "I experienced myself as separate from my changing thoughts and feelings" (Lau et al., 2006) map onto two subscales: curiosity and decentering. Items from the curiosity subscale reflect an attitude of wanting to learn about one's experiences of the present, and decentering items reflect awareness of one's experience with some disidentification and distance, rather than focusing on thoughts and feelings (Teasdale et al., 2002). Higher scores indicate greater mindfulness, curiosity, and decentering. Internal consistency for curiosity in the present study was good (α = .88). Internal consistency for decentering was unexpectedly poor (α = .588) despite assumptions of normality being met. Further inspection revealed low interitem correlations. Removal of one or more combinations of problematic items (i.e., Items 1, 4, and 8), an extreme score (n = 1), and outliers (n = 4) did not improve internal consistency for decentered awareness. Therefore, this subscale was removed.

Affect

The Positive and Negative Affect Schedule–Short Form is a self-report questionnaire that measures positive and negative affect (Watson et al., 1988). Positive affect is associated with pleasurable engagement with the environment, and negative affect reflects general distress and negative states such as anger, guilt, or anxiety. The Positive and Negative Affect Schedule–Short Form contains 20 items, measured on 5-point scales ranging from 1 (*very slightly* or *not at all*) to 5 (*extremely*). Higher scores indicate greater positive or negative affect, respectively. The measure is sensitive to momentary changes in affect and, thus, is suitable to investigate immediate effects of the VRI (Watson et al., 1988). The Positive and Negative Affect Schedule–Short Form demonstrates good internal consistency for the positive and negative affect scales (α = .89 and α = .85, respectively) and shows concurrent validity for the two-factor model (Crawford & Henry, 2004; Heubeck & Wilkinson, 2019).

Presence

The Igroup Presence Questionnaire consists of 14 items that measure the subjective sense of being present in a VE (Schubert et al., 2001). All items are scored on 7-point rating scales (1–7), with each item anchored by various opposing descriptors, for example, "I felt present in the virtual space," which has response options ranging from 1 (*fully disagree*) to 7 (*fully agree*; Schubert et al., 2001). Higher scores indicate a greater sense of presence, with items summed to produce three subscales (spatial presence, involvement, and experienced realism) and a total scale. Internal consistency for the total scale in the present study was good (α = .85).

Cybersickness

The Cybersickness Questionnaire (CSQ) is a measure of cybersickness specifically adapted to VR (Sagnier et al., 2020; Stone, 2017). It contains nine items measuring cybersickness symptoms (Stone, 2017). There are three response options for each symptom: 0 (*none*), 1 (*slight*), and 2 (*moderate*). Items are summed to produce two factors: dizziness and difficulty focusing. Higher scores on these scales indicate greater experiences of cybersickness. Internal consistency in the present study was also good for dizziness (α = .80) but lower (α = .70) for difficulty focusing.

Satisfaction

The Client Satisfaction Questionnaire, eight-item version, by Larsen et al. (1979) measures general satisfaction with an intervention (e.g., "Did you get the kind of service you wanted?"). It evaluates dimensions such as the following: quality of service, whether needs have been met, if users would recommend the service, helpfulness of the service, and whether they would use the service again. It utilizes 4-point rating scales with response options ranging from 1 (*no, definitely not*) to 4 (*yes, definitely*; Larsen et al., 1979). Items are summed with higher scores signifying greater satisfaction. Wording of the CSQ prompt was changed to "program" rather than "service" to ensure participants understood the questionnaire to improve interpretability and understanding. Internal consistency in the present study was excellent, α = .90.

User Reflections on Experience

Three open-ended questions prompted participants to provide feedback on perceived positives, negatives, and comfort experienced during the VRI. Participants typed responses into the online survey platform for subsequent qualitative analysis.

VR Technology

The low- and medium-range conditions used the VR Shinecon and BOBOVR Z6 HMDs, respectively. Both HMDs were linked to a Samsung Galaxy S10+ smartphone. The VRI was accessed through YouTube VR (360°) for each condition. The Oculus Quest 2 was used for the high-range condition. The cost and technical specifications of each VR headset are provided in Table 2.

VR Intervention

The VRI drew upon key principles and techniques from theoretical mindfulness frameworks (unified protocol by Barlow et al., 2010; Kabat-Zinn, 2015) due to the empirical evidence of its effectiveness for improving mental health (Khoury et al., 2013). Content from mindfulness intervention was adapted by the authors, delivered by a provisional psychologist (DR), and presented in the VEs using YouTube VR (see Supplemental Material). The VRI was 20 min in duration and was filmed using a 360° camera (i.e., GoPro Hero) and included two 4-min psychoeducation videos of the provisional psychologist in a therapy room, who delivered the intervention content via dialogue spoken from a script (see Supplemental Material). Additionally, each video included a brief psychoeducative text that defined and described key components of mindfulness practice (i.e., attentional focus, nonjudgment, awareness, and emotions). The final active component of the intervention was a 10-min video recording of a nature environment (i.e., a creek situation in bushland within a national park). This VE delivered

Table 2
Specifications of the Head-Mounted Displays Used in the Present Study

Name	Experimental condition	Release year	Cost (AUD)	Display resolution[a]	Head tracking DOF	Horizontal FOV	Weight (grams)
VR Shinecon	Low-range	2018	$24		3	85°	450
BOBOVR Z6	Medium-range	2019	$72		3	110°	420
Oculus Quest 2	High-range	2020	$479	1832 × 1920	6	89°	503

Note. DOF = degrees of freedom, refers to the ways an object can move within a space; FOV = field of view, represents how much virtual environment users can see.
[a] Display resolution for the VR Shinecon and BOBOVR Z6 was dependent on the smartphone (i.e., 3040 × 1440). The video resolution for the virtual environments for VR Shinecon and BOBOVR Z6 was 1280 × 480, and the Oculus Quest was 3840 × 1920.

embedded audio from a prerecorded voice-over of a guided mindfulness meditation script (Barlow et al., 2010), which was narrated by a provisional psychologist. Content of the script included a somatic body scan, breathwork (i.e., diaphragmatic breathing), and a grounding exercise (i.e., use of the five senses). The intervention was piloted in both a VR and non-VR format in a previous study (D. Rowland, 2024).

Procedure

Ethics approval was obtained through the host university's Human Research Ethics Committee. Convenience sampling was conducted through a student participation pool to recruit participants enrolled in courses that offered partial course credit for voluntary research participation. Participants were informed that the study aimed to better understand outcomes from a digital mental health program. Random allocation to one of the three conditions (low-, medium-, or high-range HMD) was achieved using a computer-generated allocation string, with participants blinded to their allocation to condition. Participants completed the first online questionnaire, which included informed consent and study information. Participants were then scheduled to complete the VRI alone in a quiet testing room. The research assistant supported participants in donning the HMD relevant to their condition by providing a brief demonstration of the technology and fitting the HMD. Participants had a moment to inspect the HMD and ask any questions before the research assistant started the intervention videos and exited the room. Upon completion of the VRI, the research assistant entered the room to collect the headset for cleaning and sanitization while participants answered the online postquestionnaire, which took 15–20 min to complete. The intervention and completion of questionnaires were completed independently and anonymously. Partial course credit was awarded for participation in the study. A risk management protocol (e.g., removal from the VE, referral to health professional service on campus) was enacted should participants experience an adverse event such as cybersickness.

Results

Quantitative

Data Preparation and Assumption Checking

Data were exported and analyzed using SPSS Version 29 (IBM, 2023). Due to the nature of online data collection and a single session intervention, no missing data were detected. All scores fell within appropriate ranges, and no floor or ceiling effects were observed. At the baseline time point, groups were deemed to be approximately equivalent with regard to mean age, $F(2, 72) = 0.356$, $p = .702$, $\eta_p^2 = .010$; distribution of gender, $\chi^2(4, 75) = 4.738$, $p = .315$, $V = 0.178$; and ethnicity, $\chi^2(18, 75) = 17.136$, $p = .514$, $V = 0.338$. The assumption of normality was assessed for dependent variables across the levels of the independent variable (i.e., low-, medium-, and high-end HMD groups). Some violations of normality (i.e., skewness) were identified, following the guidelines outlined by Tabachnick and Fidell (2007). Specifically, the CSQ dizziness scores for the medium-end HMD group exhibited positive skew, while the postintervention TMS curiosity scores showed negative skew, with one positive outlier. These findings were further validated through visual inspection of histograms.

To address the normality violations, square-root transformations were applied to both the CSQ dizziness and TMS curiosity subscales. A series of one-way analyses of variance for CSQ and mixed analyses of variance for TMS curiosity were conducted, with results compared across the original data, transformed data, and transformed data with outliers removed. None of the transformations affected the significance or interpretation of the results. Consequently, for clarity and ease of interpretation, all analyses have been reported based on the original data, with all cases retained.

Quantitative Outcomes

Mixed analyses of variance were conducted to evaluate whether different HMDs influenced participants' experiences of mindfulness and affect in the VRI. Descriptive statistics are displayed in Table 3.

Presence. At the post time point, a significant between-group difference and large effect size were observed in participants' experience of presence in the VRI, $F(2, 72) = 3.856$, $p = .026$, $\eta_p^2 = .097$, 95% confidence intervals (CIs) [0.00, 0.22], which was followed up with Tukey's pairwise post hoc test. No significant differences were found between the mid-range headset and either the high-range, $t(72) = -0.493$, $p = .615$, $d = 0.267$, 95% CIs [−11.18, 0.48], or the low-range headsets, $t(72) = -1.791$, $p = .180$, $d = 0.506$, 95% CIs [−2.02, 14.02], although a medium effect size was observed for the latter. The difference between the low- and high-range headsets was significant with a medium effect size observed, $t(72) = -2.734$, $p = .021$, $d = 0.773$, 95% CIs [−17.18, −1.14] (see Figure 1).

Cybersickness. For the first subscale of the CSQ, dizziness, no significant differences were found between groups, $F(2, 72) = 2.083$, $p = .132$, $\eta_p^2 = .055$, 90% CIs [0.00, 0.14], and a small-sized effect was observed (see Table 2). However, a significant medium

Table 3

Descriptive Statistics (Means and Standard Error) Across Time and Group for Mindfulness, Affect, Cybersickness, Satisfaction, and Presence

Outcome measure	Preintervention (N = 75)			Postintervention (N = 75)		
	Low-range (n = 25)	Mid-range (n = 25)	High-range (n = 25)	Low-range (n = 25)	Mid-range (n = 25)	High-range (n = 25)
Presence				55.08 (2.75)	61.08 (2.32)	64.24 (1.97)
Cybersickness—dizziness				1.84 (0.46)	0.84 (0.35)	0.96 (0.27)
Cybersickness—difficulties focusing				3.96 (0.39)	2.52 (0.38)	3.08 (0.89)
Client satisfaction				23.24 (0.83)	25.76 (0.71)	25.24 (0.75)
Mindfulness—curiosity	14.76 (1.01)	15.04 (1.01)	13.68 (1.01)	17.96 (0.88)	17.92 (0.88)	15.84 (0.88)
Positive affect	28.08 (1.44)	30.44 (1.44)	26.92 (1.44)	28.20 (1.55)	31.20 (1.55)	30.32 (1.55)
Negative affect	16.44 (1.00)	15.76 (1.00)	16.12 (1.00)	12.60 (0.80)	12.96 (0.80)	11.80 (0.80)

Note. Mean and standard error shown in parentheses.

effect of group was found for the second subscale, difficulty focusing, $F(2, 72) = 3.579$, $p = .033$, $\eta_p^2 = .090$, 90% CIs [0.01, 0.19]. Tukey's pairwise post hoc tests revealed significantly fewer difficulties focusing for participants in the mid-range HMD group than participants in the low-range HMD group, $t(72) = 2.654$, $p = .026$, $d = 0.751$, 95% CIs [−2.74, −0.14], with nonsignificant differences between low- and high-range, $t(72) = 1.622$, $p = .243$, $d = 0.459$, 95% CIs [−0.42, 2.18], and mid- and high-range conditions, $t(72) = -1.032$, $p = .559$, $d = 0.292$, 95% CIs [−1.86, 0.72] (see Figure 2).

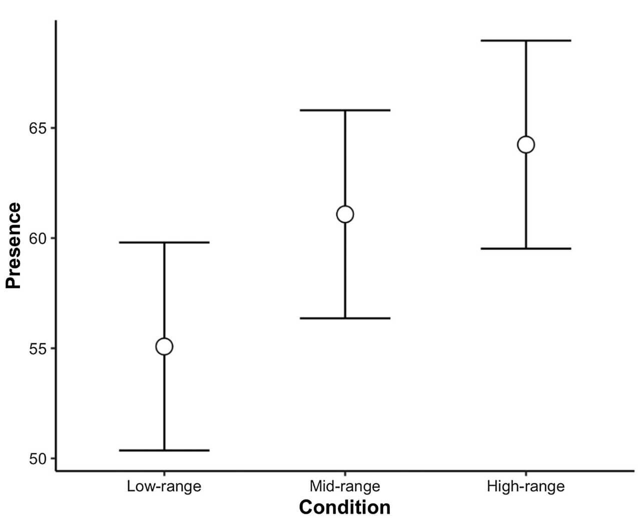
Satisfaction. No significant differences and a medium effect were found between the three groups on self-reported satisfaction with the VRI at the postintervention time point, $F(2, 72) = 3.024$, $p = .055$, $\eta_p^2 = .077$, 65% CIs [0.00, 0.20].

Mindfulness and Affect. For mindfulness—curiosity, there was a significant and large main effect of time, $F(1, 72) = 20.936$, $p < .001$, $\eta_p^2 = .225$, 90% CIs [0.09, 0.35], such that participants reported a greater experience of curiosity at the postintervention ($M = 17.24$, $SE = 0.510$, 95% CIs [16.22, 18.26]) than at the preintervention time point ($M = 14.49$, $SE = 0.58$, 95% CIs [13.33, 15.65]), regardless of condition. The main effect of group was small and not significant, $F(2, 72) = 1.470$, $p = .237$, $\eta_p^2 = .039$, 90% CIs [0.00, 0.12], nor was the interaction significant, $F(2, 72) = 0.262$, $p = .770$, $\eta_p^2 = .007$, 90% CIs [0.00, 0.04].

For in-the-moment experience of positive affect (Table 2), the main effect of time was not significant, $F(1, 72) = 3.874$, $p = .053$, $\eta_p^2 = .051$, 90% CIs [0.00, 0.15], with no main effect of condition, $F(2, 72) = 1.110$, $p = .335$, $\eta_p^2 = .030$, 90% CIs [0.00, 0.10], or interaction, $F(2, 72) = 1.918$, $p = .154$, $\eta_p^2 = .051$, 90% CIs [0.00, 0.14], observed. For experience of negative affect, the main effect of time was significant and yielded a large effect size, $F(1, 72) = 64.884$, $p < .001$, $\eta_p^2 = .474$, 90% CIs [0.33, 0.58], such that participants experienced significantly less negative affect at postintervention ($M = 12.45$, $SE = 0.46$, 95% CIs [11.54, 13.37]) than at preintervention ($M = 16.11$, $SE = 0.57$, 95% CIs [14.96, 17.25]). The main effect of condition, $F(2, 72) = 0.127$, $p = .881$, $\eta_p^2 = .004$, and interaction between time and condition, $F(2, 72) = 0.978$, $p = .381$, $\eta_p^2 = .026$, 90% CIs [0.00, 0.09], were not significant.

Figure 1

Experience of Presence in the Virtual Intervention Across Head-Mounted Display Conditions



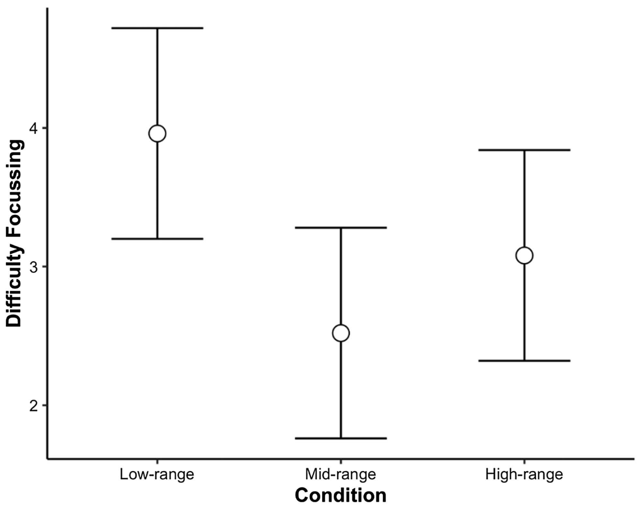
Note. Error bars represent 95% confidence intervals.

Qualitative Results

Sentiment Analysis

The sentiment analysis of the responses ($N = 346$) revealed a general prevalence of positive sentiments across the total sample. Of the total responses, 186 (54%) were categorized as positive, while 156 (46%) were categorized as negative. The frequency and number of responses for positive and negative sentiments across the different groups are summarized in Table 4. A chi-square test for independence was conducted to assess whether sentiment distribution (positive vs. negative) varied by HMD condition. A nonsignificant effect, $\chi^2(2, 342) = 1.5$, $p = .467$, $V = 0.05$, indicated that sentiment distribution was not significantly dependent on HMD condition. Group differences were observed in the high-range group, which had the largest proportion of positive responses relative to negative ones. In contrast, the low-range group produced the highest total number of responses for both positive and negative sentiments, but the distribution of sentiment types was more balanced. Among the positive sentiments, the most commonly occurring themes were "enjoyment" ($n = 31$, 16%) and "mindfulness" ($n = 25$, 13%). These sentiments were frequently reported across all conditions, with "enjoyment" being especially prevalent in the high-range group (e.g., P21—low-range condition: "I really enjoyed the nature

Figure 2
Experience of Cybersickness—Difficulty Focusing on the Virtual Intervention Across Head-Mounted Display Conditions



Note. Error bars represent 95% confidence intervals.

landscape and participating in the mindfulness activity in the virtual environment"). Regarding negative sentiments, the most common were "poor visual quality" (n = 31, 20%) and "uncomfortable headset" (n = 15, 10%). For example, one participant stated, "I would have had a better experience if the quality of the video and headset were better" (P42—low-end condition). Finally, the high-range group also reported fewer instances of these negative sentiments compared to the low- and mid-range groups (e.g., P12—high-end condition: "I liked everything").

Conceptual Analysis

A content analysis of participant responses across three HMD conditions (low-range, mid-range, and high-range) identified key themes and concepts, with co-occurring concepts counted individually (Table 5). In the low-range group, *technology* (VR headset) was the most frequently mentioned, followed by *environment* (VE) and *therapy* (mindfulness). *User* themes, particularly comfortability, were also notable. The low- and mid-range groups endorsed similar concepts, and both were highly focused on *technology*, although the specific concepts differed (i.e., video quality rather than VR headset). In contrast, the high-range group showed a more balanced distribution across themes. *User* was the most frequent theme (experience), followed by *therapy* (time/duration), *environment* (VE), and *technology* (video quality). Ranked order of themes by the number of occurrences was consistent with Fares et al. (2024). The high-range group demonstrated less focus on technological aspects, indicating that higher quality headsets allowed for a more immersive and holistic experience, with broader engagement in *user*, *therapy*, and *environment* themes.

Triangulation of Data

Quantitative sentiment analysis revealed that the high-range group reported predominantly positive sentiments (e.g., enjoyment and mindfulness), while the low- and mid-range groups showed more balanced sentiment distributions. This pattern was consistent with qualitative themes, where comfortability and video quality were prominent concerns in the low- and mid-range groups, with participants frequently mentioning VR headset and video quality (e.g., mid-range P28—"the video needed to be clearer" and "the headset could have been lighter"; low-range P6—"the headset was blurry," P12—"headset was uncomfortable," and P4—"the headset was uncomfortable to wear and the video was blurry"). These technological issues likely contributed to the negative sentiments observed in the sentiment analysis. In contrast, the high-range group exhibited a more balanced thematic distribution, with a stronger emphasis on *user* (experience) and *therapy* (time/duration), alongside fewer concerns about technological limitations. This suggests that higher quality HMDs reduce discomfort and visual issues, allowing users to engage more fully with the intervention's therapeutic and environmental aspects. Together, the quantitative and qualitative results highlight the significant role of technology quality in shaping user experiences, with higher quality VR facilitating more positive emotional responses and deeper engagement in both the user and therapeutic aspects of the intervention.

Discussion

The present study aimed to better understand the impact VR technology factors have on a mindfulness VRI, on user experiences and outcomes, across three different fully immersive and commercially available HMDs. The first hypothesis predicted that the high-range HMD would outperform the low-range HMD on presence, treatment satisfaction, and qualitative findings regarding the user experience. This prediction was partially supported. Quantitative results confirmed the high-range HMD achieved greater presence than the low-range HMD, with a medium effect size observed. This was consistent with expectations and previous literature (Filter et al., 2020; Howard, 2019; Ling et al., 2013; Navarro-Haro et al., 2017; D. P. Rowland et al., 2022; Seabrook et al., 2020; Slater & Wilbur, 1997) and implies that a high-quality, high-range HMD can assist in fostering greater presence than entry-level headsets. Contrary to predictions, no significant differences were found between groups on

Table 4
Descriptives for Positive and Negative Sentiments by Condition

	Low-range		Mid-range		High-range	
Sentiment	Frequency (%)	Responses (n)	Frequency (%)	Responses (n)	Frequency (%)	Responses (n)
Positive	51	67	50	55	57	64
Negative	49	65	42	46	40	45

Table 5
Frequency and Number of Responses for Most Commonly Occurring Concepts by Theme and Head-Mounted Display Condition

Condition	Theme	Most common concept	Frequency (%)	Response (*n*)
Low-range	User		23	57
		Comfortability	13	33
	Therapy		25	63
		Mindfulness	9	23
	Environment		24	61
		Virtual environment	4	10
	Technology		28	72
		Virtual reality headset	12	30
Mid-range	User		23	49
		Comfortability	14	30
	Therapy		15	32
		Mindfulness	5	10
	Environment		30	64
		Virtual environment	7	16
	Technology		32	69
		Video quality	5	10
High-range	User		31	55
		Experience	8	15
	Therapy		28	49
		Time/duration	7	13
	Environment		27	47
		Virtual environment	5	9
	Technology		14	26
		Video quality	8	15

treatment satisfaction. It should be noted, however, that while the results were nonsignificant, a medium effect size was still observed. This contrasts with previous literature by Bowman and Wingrave (2001), in which user satisfaction with a VR app or program was dependent on the quality of content, realism, graphical quality, and device. Scores on satisfaction were higher than previously reported cutoffs (i.e., scores greater than 20), suggesting participants were moderately satisfied with the VRI irrespective of which HMD was used. This indicates that differences may exist between the HMDs but that the present study was underpowered to identify these differences. Inspection of descriptive statistics indicates a trend toward lower treatment satisfaction for participants in the low-range HMD group, which is consistent with previous research (Filter et al., 2020). Satisfaction scores in the present study were consistent with those previously reported in a clinical outpatient sample who received traditional mindfulness to manage critical illness (Cox et al., 2019) and trauma (Evans et al., 2019). Additionally, satisfaction was also comparable to mean scores obtained from a clinically depressed sample of university students who received mindfulness-based therapy for 2.5 hr per week for 8 weeks (McIndoo et al., 2016). This finding suggests that participants were equally moderately satisfied with the VRI, irrespective of the quality of the HMD. Qualitative findings differed from qualitative results in that participants in the high-range group reported more positive and less negative feedback regarding the VRI and technology than the low- and mid-range groups; however, this may not imply the degree of satisfaction.

The second hypothesis predicted that the high-range group would report significantly higher scores on cybersickness than the low-range group (Putawa & Sugianto, 2024); however, results indicate that no significant differences were observed for difficulty focusing or dizziness. This may be explained by mixed findings regarding the relationship between cybersickness and VR technology (Weech et al., 2019). The high scores of cybersickness in the present study support Chang et al. (2020) in that cybersickness scores were higher in each of the fully immersive HMDs than what has been previously reported (Stone, 2017). Similarly to Putawa and Sugianto (2024), the technical specifications and quality of the HMDs used in this study may not be as easily distinguishable or as different as proposed in earlier research. This may be due to technological advancements in VR technology and similar quality of VR HMDs that are now available to the consumer market. Therefore, the findings could be more effectively explained by the immersive and novel aspects of VR, which enhance the sense of presence. Mean scores on the CSQ were unexpectedly higher across all conditions, compared to Stone (2017) and Sevinc and Berkman (2020), except for the mid-range and high-range conditions, which had lower mean scores compared to Stone (2017) and not Sevinc and Berkman (2020). This finding may be explained by the comparison between fully immersive HMDs, rather than different levels of immersive technology. This is consistent with Weech et al. (2019), who reported higher rates of cybersickness in more immersive technologies. It may be possible that certain items on the CSQ were endorsed based on the quality of the visual elements of the VE and less by the subjective feelings or symptoms of cybersickness. For example, difficulties focusing due to poor image quality may tap into technology-specific experiences and somatic complaints. Qualitative responses confirmed that some participants experienced symptoms like eye strain and dizziness, particularly in lower range headsets, but many responses attributed this to the quality of the VE display, which suggests device quality affects the user experience.

The third hypothesis predicted significant improvement would be reported following the VRI compared to preintervention for mindfulness, positive affect, and negative affect, with the expectation that the high-range condition would significantly outperform the low-range condition. Results from the present study partially supported this prediction in that gains in mindfulness (curiosity) occurred irrespective of HMD quality or type, with a large effect observed, and no differences identified between conditions. For in-the-moment experience of affect, positive affect improved in each of the HMD conditions, with a small effect size and no significant differences observed between groups. Postintervention effects indicate that participants experienced less negative affect, irrespective of HMD type. That is, gains were observed for mindfulness and affect across time points, achieving a medium effect size; however, there were no differences between groups on any of these outcomes. Finally, exploratory comparisons of the medium-range group were conducted with the low- and high-range groups separately. Findings revealed no significant differences, indicating that a medium-range HMD may provide a feasible "middle ground" for cost and quality.

Strengths and Limitations

This study should be considered in the context of key strengths and limitations. The study design, random allocation of participants to conditions, and participant blinding to condition were key strengths of the study. Additionally, the study highlights the importance of balancing cost and quality when considering VRIs with limited resources, such as educational or community-based settings. Findings from the study should be considered in the context of limitations. The omission of a control group may prevent clear attribution of observed effects to the intervention or to the VR technology; however, previous literature illustrates that control groups are not always needed in clinical research when pooled effects from previous studies that include a waitlist are available (Devilly & McFarlane, 2009). Prior experience and current use of mindfulness and VR were not measured, and these data would have proved useful in understanding user experiences. It is important to note that previous experience with VR is a predictor of user experiences (Chang et al., 2020; Weech et al., 2019); however, prior rates of VR experience are typically low (approximately 2.6% of Australians have engaged with VR technology; Deloitte, 2023; eSafety Commissioner, 2023), and this may have contributed to the higher CSQ scores in this study. Finally, the decentered awareness subscale of the TMS was excluded due to poor internal consistency. Novelty or degree of immersion of the VE may have affected participants' ability to attend to the task and maintain a detached view of their thoughts. Additionally, disorientation or difficulty focusing could have limited participants' ability to engage in introspection. Such relationships could be explored in future research to better understand how user experience may impact mindfulness practices in VR.

Implications and Recommendations for Future Research

These findings suggest that the recent advancements in VR technology have narrowed the gap between low-range and high-range HMDs in terms of user experience, particularly in aspects like presence and negative affect. Entry-level VR systems perform similarly; however, more positive user experiences and greater presence may be achieved in high-quality systems. Low-range HMDs may provide a user experience that is comparable to high-range HMDs, although technical specifications of the fully immersive HMDs used in this study may not have been as distinguishable as we predicted. However, it is important to recognize that the impact of VR quality on user experiences may not stem solely from psychological content but how VR technology can be leveraged and adapted to improve user experiences. Low-range HMDs are sufficient for the delivery of mindfulness VRIs and may be a strategic and cost-effective solution for the implementation and translation of VR technology in settings where resources are limited, such as education, research, and mental health. Future research should seek to compare VRIs in immersive HMD to controls and account for demographic predictors of the user experience such as previous and current experience with VR, mindfulness, and treatment. Additionally, research should seek to compare HMDs that differ more on technical specifications across a greater variety of technological factors to better understand the role of VR technology in the design and delivery of VRIs. Finally, longitudinal evaluations and clinical studies are needed to provide more robust evidence for the effectiveness, utility, and applicability of mindfulness VRIs.

Conclusion

To the authors' knowledge, no study to date has specifically compared HMD quality. Rather, the literature has focused primarily on establishing the efficacy of VRIs. The findings of this study provide useful information on the relevancy, utility, and technical specifications of VR technology for users to consider. When integrating VR in mental health interventions, consideration should be given to not only the evidence base but also the quality of VR technologies and user experiences (e.g., HMD specifications, comfort, fit, weight, eyestrain). This study contributes to the growing body of research on VR-based mindfulness interventions, suggesting that the quality of the HMD can influence certain aspects of user experience but may not significantly influence cybersickness and satisfaction with mindfulness treatments delivered in VR. Future research should explore the specific mechanisms linking mindfulness treatment content and technology, as well as the long-term effects and clinical efficacy of VR-based mindfulness interventions.

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