Journal of Computing in Higher Education
https://doi.org/10.1007/s12528-023-09393-y

Effects and acceptability of virtual reality to facilitate mindfulness practice in university students

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Accepted: 9 November 2023

Abstract

Mindfulness practices have proven to be effective for improving the mental health of many populations, including university students. However, these practices can be challenging for naive meditators. Virtual reality (VR) can create virtual scenarios that facilitate the practice of mindfulness. This study presents secondary data from a randomized controlled trial on the effects and acceptability of mindfulness-based VR environments conducted with a sample of university students. Specifically, it involved a single condition (n = 93) receiving an intervention that comprised six short mindfulness sessions in VR. Measurements were taken of participants' state mindfulness and emotional state immediately before and after the implementation of each VR environment. Sense of presence was measured subsequent to each VR environment. Furthermore, participants were asked to rate their expectations for at baseline and satisfaction with the experience after the intervention. Participants significantly improved both state mindfulness and emotional states, and they reported a moderate-to-strong sense of presence in each of the VR environments. Moreover, participants reported high expectation and satisfaction scores for the intervention. This study shows the potential of VR in mindfulness, although there is a need for more research in this area and, in particular, more sophisticated trial designs.

Keywords Virtual reality · Mindfulness · University students · State mindfulness · Emotional states · Acceptability

Introduction

The mental health of university students is an public health issue of concern. Data from a cross-national using the World Health Organization World Mental Health Surveys and involving 21 countries indicated that one-fifth of university students

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Published online: 17 December 2023

had a 12-month DSM-IV/CIDI disorder (Auerbach et al., 2016). Another cross-national study involving 8 countries reported that at least one-third of first-year university students screened positive for of one or more of the mental disorders examined in the survey (anxiety, mood or substance disorder) (Auerbach et al., 2018). Suicidal thoughts and self-harming behaviours also seem to be common among university students (Keyes et al., 2012; Mortier et al., 2018). In Spain, the country where our study was conducted, the Ministry of Universities and the Ministry of Health released the results of a recent study on the prevalence of mental health problems in a sample of 59,605 Spanish university students (Ministerio de Universidades y Ministerio de Sanidad, 2023). They revealed that one out of every two participating students had experienced depressive symptoms and moderate or severe anxiety in the previous 2 weeks, while approximately one out of every five students had suicidal thoughts and manifested clinical or severe insomnia. Moreover, half of the students reported having consulted a health professional for a mental health problem and more than half had perceived the need for psychological support for mental health problems during the previous academic term. There is evidence that mental health problems can have negative consequences on the development of university students, including impaired academic performance (Bruffaerts et al., 2018; Keyes et al., 2012), higher drop-out rates (Auerbach et al., 2016; Mojtabai et al., 2015) and future marginalization from the labour market (Niederkrotenthaler et al., 2014). Therefore, prevention and early treatment of mental health problems in university students is paramount, and universities face the great challenge of implementing interventions to help students improve their mental health (Cuijpers et al., 2019; Modrego-Alarcón et al., 2021). In this respect, mindfulness-based strategies have been suggested and recommended as means of responding to these challenges (e.g., Medlicott et al., 2021; Schonert-Reichl & Roeser, 2016).

Mindfulness is defined as the ability to stay aware of and focus attention on experiences that happen in the present moment, in an accepting, curious and non-judgemental manner (Bishop et al., 2004). Mindfulness-based programmes (MBPs) have proven to be effective for improving mental health in both clinical and non-clinical adult populations (Demarzo et al., 2015; Goldberg et al., 2022; Gotink et al., 2015; McClintock et al., 2019). Research on the effectiveness of MBPs on the university student population does not have the same degree of consolidation as in other populations, although recent systematic reviews and meta-analyses indicate the potential of mindfulness for reducing students' levels of stress, anxiety and depression, and for improving their well-being (Bamber & Morpeth, 2019; Bamber & Schneider, 2016; Dawson et al., 2019; Halladay et al., 2019; Ma et al., 2019; McConville et al., 2017; O'Driscoll et al., 2017). Despite the benefits of MBPs, focusing attention on meditation tasks can be challenging, given the large number of environmental and personal distractors (Navarro-Haro et al., 2017a, 2017b; Seabrook et al., 2020) that can hinder the practice of naive meditators such as university students. In addition, adherence to psychotherapies is a common problem among university students (Nam & Toneatto, 2016; Pedrelli et al., 2015). These considerations, together with the appeal for technologies such as VR for students (Elbyaly et al., 2023; Yu, 2021), make it important to identify new ways of practising mindfulness for this population.

Virtual reality (VR) technologies have the potential to tackle challenges related to environmental distraction by providing immersive, engaging and controlled visual and auditory software with which to practise mindfulness skills (Kosunen et al., 2016; Navarro-Haro et al., 2017a, 2017b; Piccione et al., 2019). VR allows participants to be completely immersed in an environment and able to interact with a synthetic world (Milgram & Kishimo, 1994). Clinical psychology has found VR very useful for the treatment of people suffering from a variety of mental health problems, given its potential to recreate important events in a controlled therapeutic setting (Eichenberg & Wolters, 2012; Valmaggia et al., 2016). Most of the research in this field to date has focused on the treatment of specific phobias and anxiety disorders (e.g. Carl et al., 2019; Glantz et al., 2003). However, there is growing use of this tool in the non-clinical population. VR has shown to be effective for managing and preventing psychological stress (Chandrasiri et al., 2020; Soyka et al., 2016), inducing positive emotions (Baños et al., 2012; Felnhofer et al., 2015), eliciting the relaxation response (Anderson et al., 2017; Botella et al., 2013) and facilitating the acquisition of learning skills (cognitive skills, psychomotor skills and emotional skills) (Jensen & Konradsen, 2018). The current excitement and enthusiasm for VR regards to the treatment of symptoms and the improvement of psychological well-being has led to the development of mindfulness practices in VR. A number of studies have indicated the potential benefits of VR in the field of mindfulness for both clinical and non-clinical populations. These benefits are related to the acceptability of using this technological system for the mindfulness practice (Flores et al., 2018, Gómez et al., 2017; Navarro-Haro et al., 2016, 2017a, 2017b), improvement in the adherence to MBPs (Modrego-Alarcón et al., 2021; Navarro-Haro et al., 2019), significant decreases in participants' negative mood states (e.g., anxiety, anger and depression) (Crescentini et al., 2016; Navarro-Haro et al., 2016, 2017a, 2017b, 2019; Kaplan-Rakowski et al., 2021; Tarrant et al., 2022), significant increases in positive mood states (e.g., relaxation, surprise and happiness) (Flores et al., 2018; Gomez et al., 2017; Navarro-Haro et al., 2016, 2017a, 2017b, 2019; Seabrook et al., 2020; Tarrant et al., 2022), achieving less distractibility from the process of breathing and less fatigue (Waller et al., 2021), and improvements in mindfulness scores (Navarro-Haro et al., 2017a, 2017b, 2019; Seabrook et al., 2020; Yildirim & O'Grady, 2020). Other authors did not find increases in general mindfulness scores or significant changes in negative emotion produced by VR practice (Chandrasiri et al., 2020; Seabrook et al., 2020). Nevertheless, few studies in this field include a rigorous RCT study design and large sample size, or evaluate the effects of the intervention beyond a single mindfulness exercise for a short period of time (Failla et al., 2022; Zhang et al., 2021). Worthy of mention is the study by Modrego-Alarcón et al. (2021) whose participants were randomly assigned to three different conditions: MBP, MBP + VR, and relaxation therapy. The MBP condition based on the mindfulness programme developed by García-Campayo and Demarzo (2015) and consisted of a 90-min group sessions structured around mindfulness and self-compassion held once a week over a space of 6 weeks. The MBP + VR condition was identical except for the incorporation into each session of a short mindfulness-based VR environment on an individual basis (a total of six mindfulness-based virtual reality environments were used). The relaxation therapy condition as an active control consisted

of an adapted version proposed by Bernstein and Borkovec (1973) of progressive muscle relaxation therapy complemented by visualizations (90-min group sessions, once a week over a space of 6 weeks). This study showed that the MBP conditions were more effective than the relaxation condition for reducing levels of perceived stress in the sample of university students, both at post-test and at six-month follow-up. Moreover, there was greater adherence to the mindfulness programme by participants of the MBP + VR condition compared to both MBP and control conditions.

Based on the aforementioned study by Modrego-Alarcón et al. (2021), the present work aims to assess the effects of the six mindfulness-based VR environments comprising the MBP + VR condition on the state mindfulness and emotional states of university students, as well as to evaluate their sense of presence in the landscapes and scenarios created by each environment. It also aims to ascertain the acceptability of VR (expectations of and satisfaction with the intervention) in order to facilitate mindfulness practice.

Materials and methods

Participants

This study presents secondary data from a randomized controlled trial (RCT)[1] involving 280 university students who were randomly assigned to three experimental conditions (for details regarding the sample selection criteria, procedure and primary data, see Modrego-Alarcón et al., 2021). Specifically, the sample of this study comprised 93 university students assigned to one of these experimental arms: the MBP + VR condition.

Design

The study was conducted using a within-subjects design on the MBP + VR condition of the aforementioned RCT. All participants filled out questionnaires before and after each short mindfulness-based VR session, and again after completing the intervention. A total of six short mindfulness-based VR environments were evaluated.

Procedure

The complete VR intervention consisted of six short VR sessions conducted once a week over a period of six consecutive weeks by a psychologist trained in the application of these VR environments. Prior to the use of VR, the psychologist subjected the participants to a health check. In general terms, the use of VR is not recommended for pregnant women; people suffering from hypertension, ear infections, epilepsy or vertigo; patients who have recently undergone surgery; and people who

[1] Trial registration: ClinicalTrials.gov NCT03771300 (11/12/2018).

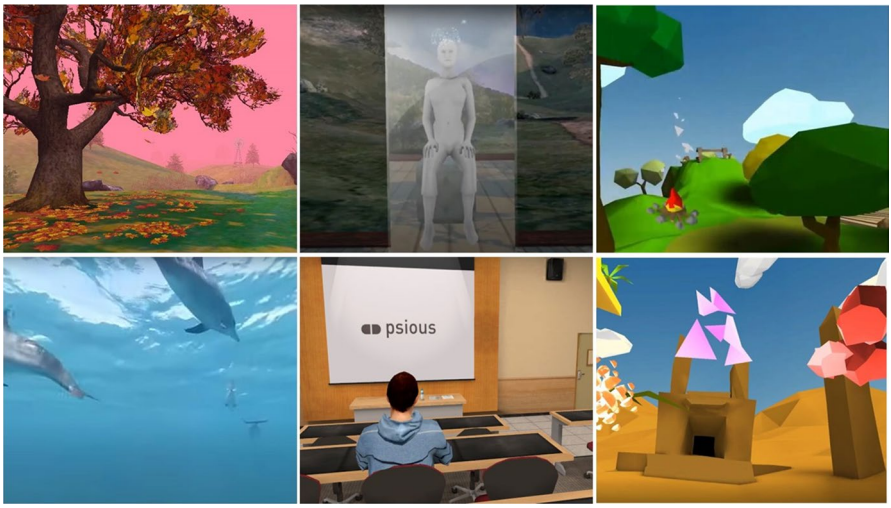

Fig. 1 Screenshots from VR environments. *Note* Top row (from left to right): VR-environment 1 (training the mind and savouring exercise); VR-environment 2 (body scanning exercise); VR-environment 3 (mindful observation exercise). Bottom row (from left to right): VR-environment 4 (compassionate coping in a difficult situation); VR-environment 5: (breathing in exams); VR-environment 6 (gratitude exercise)

suffer from cardiovascular disease, psychosis or serious mental illness. For this reason, it was ensured that none of these conditions were present. The psychologist was responsible for applying the intervention in a safe space prepared for this purpose within the university. The participants were seated on a chair and there were no interruptions.

VR mindfulness intervention

Each short VR session was applied on an individual basis and consisted of a mindfulness or compassion exercise in VR which had been designed by PSIOUS® (currently known as Amelia Virtual Care). This company offers a comprehensive VR software for mental health professionals' therapy sessions with a library of immersive environments, including mindfulness, public speaking, social situations, high places, flying and relaxation. From this wide range, our team selected six mindfulness-based VR environments consisting of core MPS practices. As detailed previously, the individual use of the mindfulness-based VR environments was part of a broader MBP, meaning that the order in which the environments were applied was determined by the main contents taught in the group mindfulness sessions in the MBP + VR condition. The average duration of the VR sessions was 7.5 min ($SD = 2.8$). The VR kit comprised a set of Samsung GEAR VR goggles, a Samsung Galaxy S6 smartphone and optional headphones (https://ameliavirtualcare.com/es/). The contents of each VR environment were as follows (see Fig. 1):

- *VR-environment 1*: *Training the mind and savouring exercise* The participant is asked to focus attention on their visual channel and their bodily sensations while observing how the leaves of a tree fall and how a lemon appears and floats continuously. The scenario takes place in a mindful walking environment (duration: 7′32″).
- *VR-environment 2. Body scanning exercise* This exercise consists of a guided body scan with visual support. The participant is instructed to become aware of their bodily sensations while different parts of the body of a virtual human figure are highlighted by means of blue bubbles (duration: 7′32″).
- *VR-environment 3: Mindful observation exercise* The participant is asked to focus attention on several elements of the natural landscape while walking. At a certain point, the participant will encounter a bonfire in the landscape that will be used to explain the concept of the 'figure of the observer of thoughts'. This concept involves observing one's own thoughts without being trapped by them, and it is represented by the smoke of the bonfire as it dissipates (duration: 8′22″).
- *VR-environment 4: Compassionate coping in a difficult situation* In the first part of the exercise, the participant is asked to identify and mentally recreate a situation from the past few weeks or months in which they experienced a negative emotion or discomfort. In the second part, the participant is instructed to accept and let go of the emotion that arose from that difficult situation. This is represented by dolphins swimming in the sea. The scenario is set in a wide ocean (duration: 10′).
- *VR-environment 5: Breathing in exams* The participant is immersed in a situation of examinations taking place at the university. The scenario includes such elements as students talking to each other prior to the exam or reviewing notes. At a certain moment, a member of the teaching staff appears and asks the students to enter the exam room. Once seated, the participant is instructed to carry out a 5-min breathing practice. The participant subsequently takes a virtual exam and can view their results, bringing the exam experience to a close (duration: 10′).
- *VR-environment 6: Gratitude exercise* In this short exercise, the participant is asked to identify three positive aspects in their life and to show gratitude for them. These three aspects are represented by three geometric figures located in the landscape. This exercise, which is set in a desert scenario, develops thankfulness and the concept of 'loving kindness' (duration: 2′40″).

Assessments

- *Socio-demographic information* socio-demographic data was collected at baseline by means of a questionnaire developed by our team for this study, including sex, age, nationality, relationships (not in a relationship, in a stable relationship), field of study (health-related, social science), academic year, education level (undergraduate, postgraduate) and employment status (employed, not in employment).
- *Experience with the use of technologies* experience with technologies was measured at baseline with a brief version of the Independent Television Com-

pany Sense of Presence Inventory (ITC-SOPI; Baños et al., 2004; Lessiter et al., 2001). Four items were selected: (1) experience with computers (none, basic, intermediate, expert); (2) knowledge about three-dimensional (3D) images (none, basic, intermediate, expert); (3) knowledge about VR (none, basic, intermediate, expert); (4) frequency of playing videogames (never; occasionally—once or twice a month; frequently—but less than 50% of days; 50% of days or more). This scale was used in a previous study (Navarro-Haro et al., 2017a, 2017b, 2019).

- *State mindfulness* state mindfulness was measured using an adaptation of the Mindful Attention Awareness Scale (MAAS-State; Brown & Ryan, 2003; Cebolla et al., 2013; Soler et al., 2012). It specifically included item numbers 3, 8, 10, 13 and 14, designated by Brown and Ryan (2003) to assess state mindfulness. Each item was rated on a seven-point Likert scale, ranging from 0 ('not at all') to 6 ('very much'). Items were reverse scored so that higher scores reflected higher levels of state mindfulness. This five-item shorter scale has been used in previous studies with good internal consistency (Navarro-Haro et al., 2017a, 2017b, 2019). State mindfulness was measured immediately before and after each short VR session. For this study, Cronbach's alpha values were good (between 0.80 and 0.90) for each use.
- *Emotional state* a visual analogue scale (VAS; Gross & Levenson, 1995) was applied to assess the intensity of different emotions immediately before and after the VR intervention. A briefer version of the original measure was used, which comprised seven emotion items (happiness, sadness, anger, surprise, anxiety, relaxation/calm, vigour/energy). Participants could choose responses ranging from 1 ('not feeling the emotion at all') to 7 ('feeling the emotion extremely'). This seven-item shorter scale has been successfully used in previous studies (Navarro-Haro et al., 2017a, 2017b, 2019; Riva et al., 2007).
- *Sense of presence* Sense of presence was measured using three items with a seven-point Likert scale ranging from 1 to 7. These three items were adapted from the Slater-Usoh-Steed Questionnaire (SUS; Slater et al., 1994). Participants were required to provide a score for each item after each VR session: (1) rate your sense of being in the virtual reality environment (1 = 'not at all', 7 = 'very much'); (2) to what extent were there times during the experience when the computer-generated world became the 'reality' for you, and you almost forgot about the 'real world' outside? (1 = 'at no time', 7 = 'almost all of the time'); (3) when you think back to the experience, do you think of the virtual reality environment more as images that you saw or more as somewhere you visited? (1 = 'something I saw', 7 = 'somewhere I visited'). The Spanish version was previously used to measure the sense of presence provided by VR, with adequate values of internal consistency (Navarro-Haro et al., 2019). This variable was measured immediately after each short VR session. In this study, Cronbach's alpha values were from good to excellent (0.80–0.94).
- *Treatment Expectation and Satisfaction Scales* (adapted from the Credibility/Expectancy Scale by Borkovec & Nau). Participants' expectations and satisfaction regarding the intervention were measured using five items ranging from 0 ('not at all') to 10 ('very much') for each scale. The items assessed the com-

plete intervention in terms of the descriptors *logical*, *satisfactory*, *recommendable*, *useful* and *aversive*. Participants completed these questionnaires at baseline (expectations scale) and post-intervention (satisfaction scale). This adaptation has been used in previous studies (e.g. ; Quero et al., 2014; Navarro-Haro et al., 2017a, 2017b).

Table 1 contains the schedule for the intervention and assessments.

Analyses

Descriptive statistics (frequencies, percentages, means and standard deviations) were calculated to explore the socio-demographic characteristics, acceptability of VR (expectations and satisfaction) and sense of presence. Chi-square (χ^2) tests were performed to explore potential differences in sample distribution for sex, education level and employment. Socio-demographic variables were included as covariables when significant differences were found in sample characteristics.

To explore pre-to-post changes in state mindfulness and emotional state outcomes for each VR environment, mixed-effect regression analyses were performed with any ad hoc imputation to account for missing data using the restricted maximum likelihood estimation (REML) procedure. A linear mixed regression was implemented for each outcome with *time* (pre-to-post VR environment) as a fixed within-group factor using the MIXED procedure (IBM SPSS version 23 for Windows), with a random intercept for subjects. An identity covariance structure was specified to model the covariance structure of the intercept. Sex, educational level and employment were included in the model as covariates. Significant effects were followed up with pairwise contrasts adjusted by Bonferroni correction for multiple comparison. The mixed-model approach is appropriate for studies with multiple time points and pre-to-post designs: it does not assume that the last measurement is stable; it does not involve any substitution of missing values with supposed or estimated values; and it is conducted using all available observations (Gueorguieva & Krystal, 2004; Salim et al., 2008; Schielzeth et al., 2020). Paired Student's t-tests were used to assess differences in total senses of presence scores after each VR environment. Effect sizes (Cohen's *d*) and the 95% confidence interval (CI) were calculated for within-group comparisons of state mindfulness and emotional state outcomes for each VR-environment and for between-group comparisons of sense of presence scores after each VR environment (Botella & Sanchez-Meca, 2015; Calin-Jageman & Cumming, 2019).

Results

Participant flow and session attendance

Of the 93 participants allocated to the MBP + VR condition, 89 (95.7%) reported data at post-intervention. With regard to the number of VR sessions attended, most participants completed four or more sessions (90.3%). More specifically, 50.5%

Table 1 Schedule of intervention and assessments

Measures	Pre-intervention assessment	Sessions												Post-intervention assessment
		Session 1		Session 2		Session 3		Session 4		Session 5		Session 6		
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
Demographic information	X													
Experience on the use of technologies	X													
State mindfulness		X	X	X	X	X	X	X	X	X	X	X	X	
Emotional state		X	X	X	X	X	X	X	X	X	X	X	X	
Sense of presence:			X		X		X		X		X		X	
Expectation and Satisfaction Scale	X													X

Table 2 Baseline characteristics of MBP + VR condition

Socio-demographic variables	MBP + VR (n = 93)
Sex, n (%)	
Females	72 (77.4%)
Males	21 (22.6%)
Age, mean (SD)	22.86 (6.41)
Nationality, n (%)	
Spanish	87 (93.6%)
Others	6 (6.4%)
Relationships, n (%)	
No relationship	46 (49.5%)
Stable relationship	47 (50.5%)
Study area, n (%)	
Health	68 (73.1%)
Social	25 (26.9%)
Course, n (%)	
1−3	73 (78.5%)
4−6	20 (21.5%)
Education level, n (%)	
Undergraduate	88 (94.6%)
Postgraduate	5 (5.4%)
Employment status, n (%)	
Employed	17 (18.3%)
Not in employment	76 (81.7%)

(n = 47) completed the six weekly VR sessions; 26.9% attended 5 sessions; and 12.9% (n = 12) attended 4 sessions. Nonetheless, 5.4% (n = 5) attended half the VR sessions (3 sessions); 1.1% attended 2 sessions (n = 1); and 3.2% (n = 3) attended one session.

The number of participants completing each environment was as follows: VR-environment 1 (n = 82), VR-environment 2 (n = 84), VR-environment 3 (n = 77), VR-environment 4 (n = 77), VR-environment 5 (n = 76), VR-environment 6 (n = 80).

Sociodemographic, and experience using VR systems at baseline

The sample mostly comprised women (n = 72; 77.4%), with a mean age of 22.9 years (SD = 6.4). Most participants were Spanish (n = 87; 93.6%). Half the students (50.5%) were in a stable relationship, and most of them were not in employment (81.7%). With regard to academic characteristics, most of the university students were studying for a degree in a health-related field (n = 68; 73.1%), such as nursing, medicine, physiotherapy and psychology. Most of them were studying for an undergraduate degree (n = 73; 78.5%) and only five participants were studying at a postgraduate level. Socio-demographic data are shown in Table 2. The results

Table 3 Experience using computers and VR systems at baseline

Items	Expert	Intermediate	Basic	None
Experience with computers	11 (11.8%)	51 (54.8%)	31 (33.3%)	0
Knowledge about 3D images	1 (1.08%)	7 (7.5%)	35 (37.6%)	50 (53.8%)
Knowledge about VR	1 (1.1%)	7 (7.5%)	34 (36.6%)	51 (54.8%)
Frequency of playing videogames	50% of days or more	Frequently	Occasionally	Never
	5 (5.4%)	7 (7.5%)	34 (36.6%)	47 (50.5%)

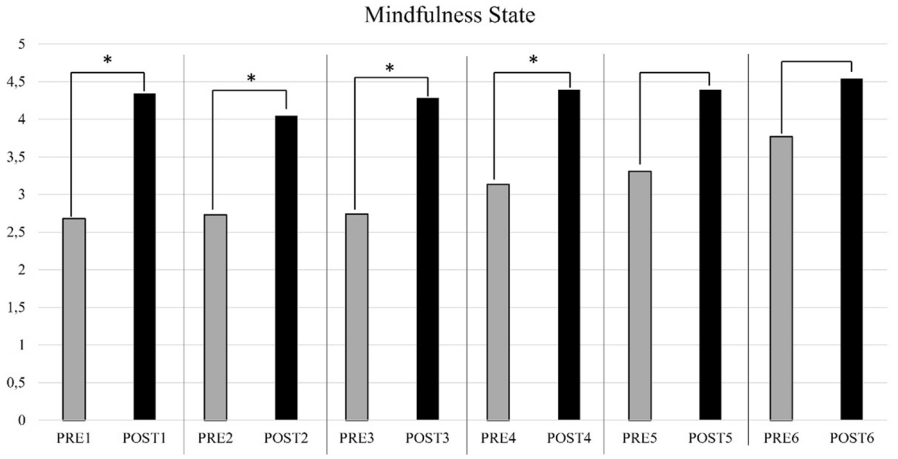

Fig. 2 State mindfulness scores for each VR-environment pre-to-post. *VR* virtual reality environment. *Sig. level was $p < .001$

showed significant differences for sex ($\chi^2(1) = 28.0$; $p < 0.001$), educational level ($\chi^2(1) = 74.1$; $p < 0.001$) and employment ($\chi^2(1) = 37.4$; $p < 0.001$).

As shown in Table 3, most participants reported an intermediate amount of experience in the use of computers (54.8%) and basic (little) or no knowledge regarding 3-D images (91.4%) and VR systems (91.4%). Furthermore, most participants did not usually play videogames (87.1% reported occasionally or never).

Effects of VR on mindfulness practice

Mindfulness

Participants reported higher *state mindfulness* after each VR session (Fig. 2). Results showed significant pre-to-post differences for each VR environment. Means, standard deviations, F- and *p*-values, effect sizes, and the 95% CI for state mindfulness (MAAS-State) before and after VR sessions is provided as Supplementary Information (SI) (Table 7).

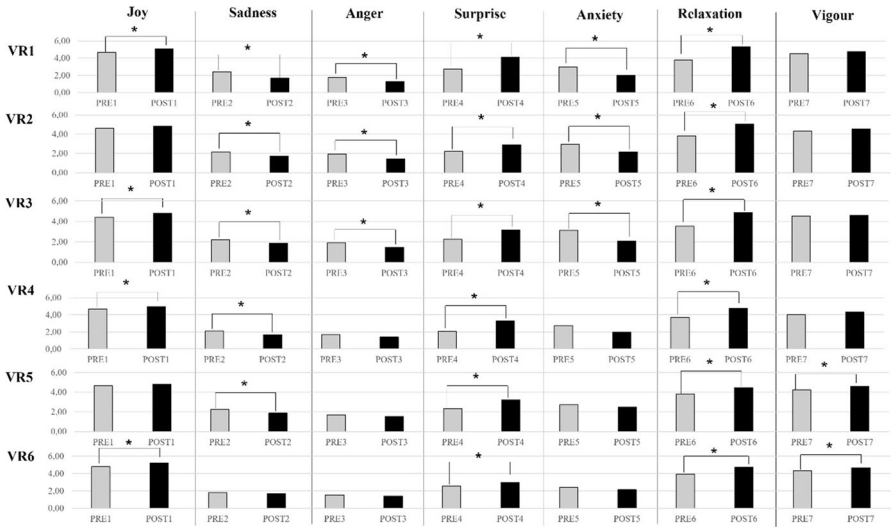

Fig. 3 VAS scores for each VR environment pre-to-post. *Note VR* virtual reality environment. *Sig. level was $p < 0.001$

Emotional state

With regard to emotional state, significant pre-to-post increases ($p < 0.001$) were found after participants were subjected to each *VR-environment.* Figure 3 and Table 4 illustrate these results. Means, standard deviations, and mean differences for emotional state before and after VR sessions are provided as Supplementary Information (SI) (Table 8). Significant covariables are detailed in Table 4.

Sense of presence

Results of descriptive statistics indicated medium-to-high scores for the s*ense of presence* outcome after each VR environment based on mindfulness means ranging from 3.70 to 5.50; possible range 1–7 (Table 5).

Comparisons between the overall *sense of presence* outcome showed statistically significant differences between VR-environments (Table 6).

Expectations and satisfaction

Results of descriptive statistics revealed high scores on all expectation and satisfaction measures (from 8.15 to 9.27) regarding the MBP + VR condition, except *aversive*, which obtained low scores. Specifically, prior the intervention (n = 93), participants reported high level of expectation in terms of *logical* (M = 8.23; SD = 1.24), *satisfactory* (M = 8.35; SD = 1.30), *recommendable* to another friend

Table 4 Statistically significant pre-to-post changes for emotional state after VR-environments

VR-environment	Comparisons and values	Significant covariables
VR1	Joy (F(1, 81) = 18.70; $p < .001$; d = − .37; 95% CI − .56, − .19) (↑) Surprise (F(1, 81) = 50.13; $p < .001$; d = − .90; 95% CI − 1.17, − .64) (↑) Relaxation (F(1, 80.39) = 84.87; $p < .001$; d = − 1.10; 95% CI − 1.41, − .80) (↑) Sadness (F(1, 81) = 63.04; $p < .001$; d = .56; 95% CI .39, .73) (↓) Anger (F(1, 81) = 25.70; $p < .001$; d = .44; 95% CI .24, .64) (↓) Anxiety (F(1, 81) = 42.00; $p < .001$; d = .64; 95% CI .39, .88) (↓)	
VR 2	Surprise (F(1, 80) = 18.75; $p < .001$; d = − .55; 95% CI − .81, − 30) (↑) Relaxation (F(1, 82.8) = (47.35); $p < .001$; d = − .83; 95% CI − 1.10, − .56) (↑) Sadness (F(1, 83) = 26.68; $p < .001$; d = .35; 95% CI .20, .50) (↓) Anger (F (1, 83) = 17.13; $p < .001$; d = .36; 95% CI .16, 56) (↓) Anxiety (F(1, 83) = 30.38 $p < .001$; d = .47; 95% CI .28, 66) (↓)	Employment → anxiety (F(1, 80) = 9.263; $p < .01$)
VR 3	Joy (F(1, 76) = 7.41; $p < .01$; d = − .27; 95% CI − .47, − .06) (↑) Surprise (F(1, 76) = 18.43; $p < .001$; d = − .68; 95% CI − .95, − .40) (↑) Relaxation (F(1, 76) = 43.72; $p < .001$; d = − .87; 95% CI − 1.17, − .58) (↑) Sadness (F(1,76) = 15.14; $p < .001$; d = .28; 95% CI .12, .44) (↓) Anger (F(1, 76) = 17.22; $p < .001$; d = .36; 95% CI .17, .56) (↓) Anxiety (F(1,76 = 61.21; $p < .001$; d = .70; 95% CI .48, .92) (↓)	Employment → Anger (F(1, 73) = 6.55; $p < .05$) → Anxiety (F(1, 73) = 4.79; $p < .05$) → Relaxation (F(1, 73) = 12.33; $p < .01$)
VR 4	Joy (F(1, 76) = 4.35; $p < .05$; d = − .23; 95% CI − .42, .03) (↑) Surprise (F(1, 76) = 35.18; $p < .001$; d = − .94; 95% CI − 1.23, − .65) (↑) Relaxation (F(1, 75.94) = 17.94; $p < .001$; d = − .68; 95% CI − 1.00, .36) (↑) Sadness (F(1,76 = 17.56; $p < .001$; d = .38; 95% CI .18, .58) (↓) Anger (F(1, 76) = 9.30; $p < .01$; d = .27; 95% CI .08, .47) (↓) Anxiety (F(1, 76) = 19.35; $p < .001$; d = .52; 95% CI .25, .78) (↓)	Employment → Anger (F(1, 73) = 10.15; $p < .01$) → Anxiety (F(1, 73) = 4.54; $p < .05$) → Relaxation (F(1, 71.98) = 7.48; $p < .01$)
VR 5	Surprise (F(1,75) = 22.16; $p < .001$; d = − .60; 95% CI .85, .34) (↑) Relaxation (F(1, 75) = 9.99; $p < .01$; d = − .41; 95% CI − .68, − .14) (↑) Vigour (F(1, 73.46) = 73,46; $p < .01$; d = − .25; 95% CI − .43, − .08) (↑) Sadness (F(1, 75) = 9.29; $p < .01$; $d = .26$; 95% CI .07, .44) (↓)	Sex → Joy (F(1, 73.07) = 4.933; $p < .05$) → Relaxation (F(1, 72) = 5.83; $p < .05$)

Table 4 (continued)

VR-environment	Comparisons and values	Significant covariables
VR 6	Joy (F (1, 78.47; $p < 0{,}05$; d = − .27; 95% CI − .43, − .10) (↑) Surprise (F (1, 78.31 = 5.4; $p < .05$; d = − .28; 95% CI − .50, − .06) (↑) Relaxation (F (1, 78.82 = 14.82; $p < .001$; d = − .46; 95% CI − .70, − .22) (↑) Vigour (F (1, 77.67) = 6,67; $p < .05$; $d = -.23$; 95% CI − .38, − .08) (↑)	Education → *vigour* (F(1, 75.85) = 4.06; $p < .05$)

VR virtual reality environment, ↑ significant increases, ↓ significant reductions

Table 5 Sense of presence scores for each VR-environment

Items	VR 1 M (SD)	VR 2 M (SD)	VR 3 M (SD)	VR 4 M (SD)	VR 5 M (SD)	VR 6 M (SD)
I had a sense of being there (possible range: X–Y)	5.29 (1.29)	4.73 (1.51)	5.25 (1.43)	5.16 (1.62)	5.50 (1.39)	4.58 (1.64)
To what extent were there times during the experience when the virtual environment was reality for you? (possible range: X–Y)	4.74 (1.53)	4.19 (1.65)	4.92 (1.66)	4.73 (1.83)	5.00 (1.77)	4.24 (1.78)
The virtual environment seems to me to be more like something I saw or somewhere I visited (possible range: X–Y)	4.55 (1.82)	3.86 (1.73)	4.58 (1.87)	4.64 (1.96)	5.00 (1.73)	3.95 (1.95)
Total score (possible range: X–Y)	4.71 (1.21)	4.15 (1.35)	4.78 (1.40)	4.7 (1.75)	4.99 (1.46)	4.2 (1.62)

M mean, *SD* standard deviation, *VR* virtual reality environment

Table 6 Statistically significant comparisons for overall sense of presence among VR-environments

VR-environment	Comparisons and values
VR1	> VR 2 (t(73) = 3.72; $p < .001$; $d = .43$; 95% CI .13, .74) > VR 6 (t(67) = 2.88; $p < .01$; $d = .36$; 95% CI .05, .67) < VR 5 (t(78) = .021; $p < .05$; $d = -.21$; 95% CI − .52, .10)
VR 2	< VR 3 (t(68) = − 3.04; $p < .01$; $d = .-.46$; 95% CI − .77, − .14) < VR 4 (t(70) = − 2.92; $p < .01$; $d = -.35$; 95% CI − .66, − .44) < VR 5 (t(69) = − 4.65; $p < .001$; $d = .60$; 95% CI − .91, − .28)
VR 6	< VR 3 (t(65) = 2.52; $p < .05$; $d = -.37$; 95% CI − .69. − .06) < VR 4 (t(67) = 4.553; $p < .001$; $d = -.51$; 95% CI − .83, − .19), < VR 5 (t(71) = 2.83; $p < .05$; $d = -.30$; 95% CI − .61, .02)

VR virtual reality environment

(M = 8.54; SD = 1.29) and *useful* (M = 8.18; SD = 1.46), and low scores for *aversive* (M = 1.19; SD = 1.73).

After the intervention (n = 89), high satisfaction scores were obtained in terms of *logical* (M = 8.76; SD = 1.01), *satisfactory* (M = 9.04; SD = 1.04), *recommendable* to another friend (M = 9.27; SD = 1.13) and *useful* (M = 8.35; SD = 1.04), and low scores for *aversive* (M = 1.20; SD = 1.83). In addition, participants reported a high perceived usefulness of VR for practising mindfulness (M = 8.15; SD = 1.95).

Discussion

This study offers data on the potential of mindfulness-based VR environments, particularly in terms of improving participants' state mindfulness and emotional state. We observed that participants showed significant improvements with large effect sizes in intra-group differences when comparing state mindfulness scores before and after the sessions (except for the last environment, which showed a moderate effect size). Other studies have also shown significant increases in state mindfulness after a single session or several sessions of mindfulness using VR among participants who were expert meditators (Navarro-Haro et al., 2017a, 2017b) and non-expert meditators (Chandrasiri et al., 2020; Navarro-Haro et al., 2019; Seabrook et al., 2020; Tarrant et al., 2022). Since higher state mindfulness can lead to increased trait mindfulness (Kiken et al., 2015), our findings indicate that using these strategies on university students may help them to be more present in everyday life (i.e. to mindfulness state) and to promote a tendency to live "mindfully" (i.e., trait mindfulness), by being present (attentional component) and open to experience without automatically reacting to internal or external experiences, and managing them with curiosity and kindness (attitudinal component of mindfulness). The embodiment of these skills (i.e., higher state and trait mindfulness) could be a powerful emotion-regulation strategy of for university student, offering a protective effect their mental health. In this respect, several studies have supported the practice of mindfulness as an effective emotional regulation strategy linked to wellbeing and mediated and/or predicted by state and trait mindfulness for both the general population and university students

(Baer et al., 2012; Campos et al., 2016; Hanley et al., 2015; Medlicott et al., 2021; Zimmaro et al., 2016; Zubair et al., 2018). This agrees with data found by Klainin-Yobas et al. (2016) that showed mindfulness to be the strongest predictor of psychological well-being among university students. Therefore, psychological interventions that include strengthening mindfulness skills are highly recommended to promote psychological well-being among undergraduate students.

VR is presented as an adequate tool with which to develop mindfulness skills and to facilitate mindfulness practice in university students. Our findings are congruent with those studies supporting the efficacy and acceptability of VR for training mindfulness and, thus, developing both trait and state mindfulness (e.g. Chandrasiri et al., 2020; Navarro-Haro et al., 2017a, 2017b). Moreover, the present study adds valuable data to this field og research by supporting the uselfulness of VR for facilitating mindfulness in university students, who are generally immersed in digital technologies in their daily lives and university education. However, it is important to mention that despite the myth that university students master technologies because they are considered native users" we found that most of our sample had not experience with VR systems, which is congruent with studies concluding that university students did not feel consider themselves competent with regard to technology and that university students often experience unsatisfactory realities in encounters with digital technology. (e.g., Selwyn, 2016; Tugun et al., 2020). In this light, our findings suggest good acceptability among the university students for the use of VR to practise mindfulness and with high levels of satisfaction.

We suggest two-fold use for VR to enable mindfulness practice in university studentsOn the one hand, the VR system may be helpful teaching mindfulness as educational tool for providing an introduction to what mindfulness is and enhancing the practice by giving users a higher sense of presence. This is in agreement with studies supporting the notion that VR helps participants to practise mindfulness skills (e.g. Navarro-Haro et al., 2017a, 2017b, 2019), and data found in the present study showing high levels of sense of presence. On the other hand, using VR systems to practise mindfulness may work by improving participants' acceptance of the intervention. VR is an attractive and immersive environment that can help participants to visualize complex concepts, create interactive simulations, and allow them to master practical skills in a controlled environment. These suggestions are in line with studies pointing out that the use of immersive technologies in higher education fosters active and engaging learning by students (Karakozov et al., 2020, as cited in Sviridova et al., 2023). In general, our sample of 93 university students accepted the use of VR as a technique for the practice of mindfulness. Participants reported high expectations before starting, as well as high satisfaction and good usefulness scores after fully completing the intervention.

Findings from this study showed significant changes in the emotional state of the participants after the VR sessions, generally increasing positive emotional states (i.e. happiness, surprise, relaxation/calm, vigour/energy) and reducing negative emotional states (i.e. sadness, anger, anxiety). These results are congruent with studies supporting the efficacy of mindfulness for promoting positive states, both with and without the use of VR to facilitate the practice (Allen et al., 2021; Navarro-Haro et al., 2017a, 2017b, 2019). The use of digital technologies

and immersive environments to induce an emotional state is widely demonstrate (e.g. Jadhakhan et al., 2022), which leads us to suggest that when combined with mindfulness practices, they become a potential tool for emotion regulation, one that is particularly helpful for university students because the virtual environment provides a secure space in which handle emotions using visual and auditory cues, easily giving rise to positive states. Given the studies that show a relationship between difficulties with regulating emotions and different mental health problems (i.e. impulsive behaviours, depression, stress) and lower wellbeing in university students (e.g. Miller & Racine, 2022; Rufino et al., 2022), its importance for university students must be highlighted.

In this regard, a number of authors have highlighted the key role of psychological strengths (e.g. helpful coping strategies, emotion intelligence, adaptative emotional regulation strategies, optimism) as being related to better levels of wellbeing among students and suggest that fostering those factors would act as buffers and protectors of mental well-being. Given the evidence pointing to mindfulness being an effective tool for developing several psychological strengths (e.g. Allen et al., 2021; Pang & Ruch, 2019) it can be seen as a potential approach for the prevention of mental health problems and the promotion of mental well-being in university students.

Another factor that promotes wellbeing among university students is the devilment of strong and supportive social networks. According to Campbell et al. (2022), students who are prepared and able to adjust to the changes presented by move into higher education also experience better mental health. Different studies have shown how mindfulness develops openness to experience, prosocial behaviours and a greater sense of connection with others, which may be an underlying mechanism of this strategy that helps university students in this endeavour at this vital stage (Adair et al., 2018; Quaglia et al., 2015). This is congruent with findings from Rehman et al. (2023) indicating that social connectedness and self-esteem perform as a mediating role in the link between mindfulness and psychological well-being.

Our study, highlights the differences found in emotional states depending on the VR environment presented, which makes further research necessary to explore the emotional changes associated with the different types of mindfulness practices applied in each VR environment. Consideration must be given to differences between the environments. We hypothesize that certain variables related to the VR environments used and also to the application context may have influenced these scores (e.g. the initial impact produced by the first environment received, the different duration of the scenarios, the distinct types of mindfulness practices, and familiarity with the situations generated by the environments).

One of the main strengths of this study is the implementation of six mindfulness sessions in VR (once a week over a period of six consecutive weeks). To date, the literature shows the prevalent use of a single VR session (Failla et al., 2022). We believe that more consecutive immersion periods can help enhance the effects of VR to facilitate mindfulness practice. Moreover, we used six VR environments based on different types of mindfulness practices (savouring, body scan, mindful observation, compassionate coping, breathing and gratitude). This wide range of practices provides a broader vision of the main practices that comprise the MBPs. Future studies

should analyse the potential differential effects of different types of mindfulness practices.

Limitations and next steps

Although the findings are encouraging, this study has important limitations. First, the absence of a control group limits the conclusions that can be drawn. The use of RCT designs would be suitable (Failla et al., 2022; Navarro-Haro et al., 2017a, 2017b). Some examples of control group tasks that have been used in other studies instead of VR are mindfulness audio tracks, video-based meditation, and immersive virtual environments whose contents elicited a high level of stress (Chandrasiri et al., 2020; Crescentini et al., 2016; Kaplan-Rakowski et al., 2021; Tarrant et al., 2022). On the other hand, only self-report measures were used in this study, and the assessed variables were not followed-up at later timepoints. The incorporation of neurophysiological measurements (ECG, EEG and EMG) into the experimental procedure, as well as the use of follow-up re-evaluations at three to six months after the end of treatment would help to better understand the effects of VR (Failla et al., 2022). Finally, students' characteristics (i.e., sociodemographic data) which may differentiate them from other populations—and additional mediator outcomes (e.g. self-compassion, Ko et al., 2018; and self-esteem, Bajaj et al., 2016) should be taken into consideration in future studies.

There are also a number of challenges to be considered. In our study, technological limitations (software updates, problems with transmission or preloading of materials) were experienced in the intervention and may have affected the results. Moreover, the individual use of VR goggles slowed down the application of this intervention. New immersive systems such as 3D environments that allow collective implementation should be considered for future studies. On the other hand, we cannot overlook the comfort of participants during VR sessions (Chandrasiri et al., 2020) and the effect of cybersickness, i.e. the feeling of continuously moving despite being still, which is often accompanied by symptoms such as nausea, eyestrain and dizziness (Wiederhold & Bouchard, 2014). Although some participants in our study reported eyestrain and dizziness, as well as discomfort caused by the pressure exerted by the the Samsung GEAR VR goggles, we did not collect this information in a systematic way.

Despite these limitations and challenges, integrating VR into mindfulness holds great potential, such as improving attrition rates for MBPs (Modrego-Alarcón et al., 2021; Navarro-Haro et al., 2019). What is more, VR can be used both to learn how to practise mindfulness and for daily home-based mindfulness practice (Flores et al., 2018; Gomez et al., 2017; Navarro-Haro et al., 2017a, 2017b; Xu et al., 2023). This is very important, given that failure to consolidate practice has been clearly established as a cause for undermining the benefits of MBPs (Crane et al., 2014; Dumville et al., 2006), and VR is in the process of becoming widely available to mainstream consumers at an affordable price (Navarro-Haro et al., 2017a, 2017b). Since very limited research has been conducted to date, it is proposed that future research studies continue to evaluate the possibilities of VR in this area.

Conclusions

VR is presented as an effective and acceptable tool to facilitate mindfulness practice in university students by of improving their state mindfulness, changing their emotional state and giving them a high sense of presence during the practice. Therefore, the practice of mindfulness supported by VR is highlighted as a potential tool for the prevention of mental health problems and promotion of mental well-being given that it improves their emotional state in the short term and may have a longer-term influence by developing students' skills and strengths for coping with difficulties and regulating their emotions.

The implementation of these kind of prevention strategies in university students covers a social need that is considered as a public health issue owing to the evidence showing that university students experience various stressors that may negatively affect their psychological wellbeing (e.g. Campbell et al., 2022). Findings from this study support the growing literature reporting that mindfulness interventions are acceptable and effective for university students and can support academic study and promote psychological strengths as a protector of mental health and affecting well-being. Moreover, using VR may improve acceptance of the intervention and facilitate the practice of mindfulness in naïve/novices meditators because this tool gives users a higher sense of presence in a secure, visually attractive and immersive environment.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12528-023-09393-y.

Acknowledgements JMM has a "Miguel Servet" research contract from the ISCIII (CP21/00080). JMM is grateful to the CIBER of Epidemiology and Public Health (CIBERESP CB22/02/00052; ISCIII) for its support.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature.

Declarations

Conflict of interest The authors declare that they have no financial or other competing interests.

Ethical approval All participants included in the study provided written informed consent. The participants did not receive any remuneration for their involvement in the study. Advanced Encryption Standard (AES) strategies including data encryption and the use of personal passwords were implemented in order to guarantee the protection of personal information. All collected data were processed anonymously and were only used for the purposes of the study. Ethical approval was obtained from the Ethics Committee of the corresponding regional authority (Ethical committee of Aragon, Spain, registry number PI18/325). All procedures performed in this study involving human participants were in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments, or comparable ethical standards.

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