The University of Tehran Press

Journal of Cognitive Science Research

2025, 1(2), 15-29

Home Page: https://jcsr.ut.ac.ir/

Psychophysiological Responses to Mindful Equanimity Induction in Virtual Reality: An Exploratory Study

Maryam Abbasi Sooreshjani [1], **Nima Ghorbani** [1*], **Meghedi Vartanian** [2]

1. Department of Psychology, Faculty of Psychology and Educational Sciences, University of Tehran, Tehran, Iran.
2. Department of Neurology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany.

***Corresponding Author:** Professor, Department of Psychology, Faculty of Psychology and Education, University of Tehran, Tehran, Iran. Email: nghorbani@ut.ac.ir

ARTICLE INFO

Article type:
Research Article

Article History:
Received: 03 May 2025
Revised: 19 May 2025
Accepted: 10 Jun 2025
Published: 01 Jul 2025

Keywords:
Equanimity, HRV, Mindfulness, Psychophysiological Responses, Virtual Reality

ABSTRACT

Equanimity, as a critical feature of well-being can be strengthened and Virtual reality (VR) can be employed to cultivate this capacity. No previous study has directly investigated the impact of different equanimity practices within VR and compared people's preferences for different practices. This study was conducted to explore whether practicing equanimity within three VR scenarios can increase mind-body calmness. Three VR scenarios (<10 min) were developed. A within-subject study (n=75) was designed to assess impact of these practices in improving calmness indices. Participants were exposed to VR practice sessions combining sound of a teacher and three animation environments including Mountain, Ocean, and Sky facing with changes during a year or day. Participants' experience of each session was assessed using heart rate variability (HRV), respiratory rate, and self-reported ratings. Subjective state anxiety was also assessed at baseline and after the end of three VR sessions. Physiological indices were improved in Ocean practice compared to baseline and two other practices. Results showed that physiological indices during practices were correlated with self-reports of mindfulness, self-knowledge, and interoceptive awareness (p<.05). A significant reduction was observed in self-reported assessment of state anxiety. Generally, VR practices of equanimity were shown to induce mind-body calmness.

Cite this article: Abbasi Sooreshjani, M., Ghorbani, N., & Vartanian, M. (2025). Psychophysiological Responses to Mindful Equanimity Induction in Virtual Reality: An Exploratory Study. *Journal of Cognitive Science Research*, *1*(2), 15-29. doi:10.22059/jcsr.2025.394621.1011

Publisher: University of Tehran Press
DOI: https://doi.org/10.22059/jcsr.2025.394621.1011

Introduction

The mindfulness construct has received increasing attention in recent years. According to this notion, it would be better to cultivate inner consciousness through acceptance and compassion instead of outsourcing to create desired external conditions of well-being and happiness (S. L. Shapiro, Jazaieri, & de Sousa, 2009). Happiness in the absence of pleasure is also referred to as "equanimity" (Bokenkamp, 2005; Harvey, 2012). Mindful equanimity is defined as mind's ability to face changes and challenges of life while maintaining calmness, simultaneously having exact knowledge of one's own and others̉ needs as well as environmental necessities (Goldstein & Kornfield, 2001).

Concept of equanimity has been recently adopted from Eastern traditions to have a new holistic look at suffering and well-being (Wallace & Shapiro, 2006). From the Buddhists̉ perspective, cultivating equanimity capacity is necessary to reduce suffering and to attain long-lasting happiness. This quality of mind influences emotional and physiological responses to a stressor (Stellar, Manzo, Kraus, & Keltner, 2012). For example, it has been shown to have benefits like decreasing mental and physiological agitation (e.g., (Ayduk & Kross, 2008, 2010). While this quality is investigated in meditation centers, it is rarely integrated into psychological research. Thus, innovative and easily achievable teaching tools are required with a focus on cultivating equanimity. Some practices have been introduced in the literature for developing equanimity capacity that can be quickly delivered in an immersive virtual reality (VR). Herein, the following definition of equanimity is used: approaching pleasant, unpleasant and neutral sensory/cognitive experiences with no preference (Desbordes et al., 2015).

Meditation in general and mindfulness-related practices in particular (including equanimity) have been shown to be effective techniques for treating a wide range of difficulties (Parsons, Crane, Parsons, Fjorback, & Kuyken, 2017). However, they can be challenging for beginners. Beginner meditators have been suggested to use system applications helping them to focus effectively on meditation assignments and eliminate other audio and visual distractors, especially in busy environments. Current technologies like VR environment can be a useful tool in teaching mindfulness-related practices and overcoming these barriers. VR technology also offers a deep sense of presence in comparison with other media and provides a safe place for practicing mindfulness and cultivating reflective self-awareness (Sliwinski, Katsikitis, & Jones, 2017).

VR has great benefits for treatment because it can create a sense of presence of mind/body, as a fundamental quality of mindfulness. This quality can rarely be achieved by imagination (Riva et al., 2015). In fact, VR essentially provides a place where a person can live and experience. In this regard, Baños et al., (2015) compared sense of presence between virtual and imaginary spaces. Participants were randomly allocated to one of two conditions, virtual versus imaginary environment, and subjective perception of presence was investigated at three times. They indicated that participants in "imaginary" environments expressed a decreased sense of presence, while those in virtual spaces reported the opposite. Freeman et al., (2004) investigated influence of VR on sense of presence in context of relaxation teaching. They showed that VR-based relaxation training induced greater sense of presence than narrative-based relaxation training. That is, VR seems to enable the users to "stay there" over time. In fact, VR can provide an experiential form of imagery that can be effective in inducing emotional responses at the same level as reality (Vincelli, Molinari, & Riva, 2001). This technology can be applied for experiencing different identities and other unexperienced aspects of self (Baños et al., 1999).

Recently, researchers have increasingly applied VR environments in the field of mindfulness and they have designed VR-based therapies for treating psychological disorders (e.g., (Seol et al., 2017)). For example, Meditation Chamber as a combination of VR and biofeedback (Shaw, Gromala, & Seay, 2007) provides relaxation and mindfulness training to participants. The

RelaWorld (Kosunen et al., 2016) was designed for meditation training using different scenarios to engage players in practice. Neurofeedback was combined with VR to visualize body scan and focused attention practices and their physiological effects.

Although, some physiological indices have also been studied for showing physical changes during practice of mindfulness, to the best of our knowledge, no study has used heart rate variability (HRV) to quantify physical indicators of equanimity during mindfulness practice. Particularly, HF (power in high frequency range), an index of parasympathetic activity has also been considered as an indicator of equanimity (Desbordes et al., 2015).

Herein, brief and accessible forms of equanimity training were introduced and studied in VR technology to make training available for novice users. Three VR-based equanimity practices (Ocean, Mountain, and Sky) were introduced where trainee was taught to keep calmness while confronting unpredictable situations and environments and these three practices were compared regarding their efficacy in reducing (psychological and physiological) stress and inducing sense of presence. Popular psychophysiological markers of this capacity were also measured including heart rate (HR), respiratory rate (RR), and HRV (Desbordes et al., 2015). These three practices are introduced in the following.

A mountain is among the images often applied to show equanimity. It remains still, centered, and quiet through changing climate and time. In this practice, a person is instructed to vividly imagine a mountain that he knows and likes with its stability and grounded presence. After some moments of shaping and holding that image in his mind, he can imagine bringing it inside himself and becoming a mountain, sitting in a calm and still position like a mountain, and observing all the changes in weather and seasons, etc. Just like a mountain withstanding changes and challenges, all of us experience different thoughts, feelings, and life adversities. This practice helps a person to deeply feel calmness and stillness in the middle of internal and external constant changes (Pollak et al., 2014). According to Kabat-Zinn, by feeling oneself as a mountain, one can be linked up with strength and stability of mountain within the ever-changing thoughts, images ,and emotional storms (Kabat-Zinn, 1994). Furthermore, another equanimity-strengthening meditation that can be taught for unstable moods and times is based on metaphor of stillness beneath waves of the lake or ocean (Pollak, Pedulla, & Siegel, 2014). This practice uses metaphor of centeredness beneath wild waves of the sea or ocean to cultivate equanimity. This practice was designed for managing distressful times like illness, grief, or loss. A person is instructed to visualize a boat with an anchor in a deep harbor while he is present in a sunny day with blue sky and tranquil sea. After a while, dark clouds come and cover the sky, and winds and rain start to make huge waves in the sea. Then, he imagines that he can drop into the sea allowing his attention to be focused on the boat’s anchor and resting there in a tranquil and still point in the middle of storm. Another related metaphor is visualizing the mind as a sky. In this practice, a person is instructed to imagine a vast sky. Sky might be occupied with different contents including sun, rain, and snow every day and with moon and stars every night allowing everything comes and goes, accepting change and not resisting against it. The sky is always present no matter what content is here (Pollak et al., 2014). These practices can be used for meditation beginners and are more effective when accompanied with concentration practices (e.g., awareness of breath) (Pollak et al., 2014).

Although, these three meditations seem to vary in different ways, they have the same basic logic that is building the capacity of being open to changing aspects of life with balance. General aim of this study was exploring whether practicing equanimity within these three VR scenarios can improve emotional and physiological calmness of participants compared to baseline. Therefore, two hypotheses and one question were set forth: (a) VR-based equanimity practices can be induce psychological and physiological calmness, (b) higher levels of mindfulness-related capacities are associated with higher levels of physiological calmness during equanimity practices, and (c) Which practice is the most preferable one based on users' self-ratings of presence?

Method

Participants

A within-subject design of study was used where 76 participants (including 47 females) aged between 20 - 49 (M=25.6) years old were recruited through advertisements at the University of Tehran. Eligible participants had no fear of height (acrophobia) and sea. They were exposed to three meditation practices for cultivating equanimity.

Materials

Instrument and Scenarios of VR

All three scenarios (Sky, Ocean, and Mountain) were based on metaphors of equanimity and adopted from imagery-based equanimity practices (Kabat-Zinn, 1994; Pollak et al., 2014). VR environment was created using Unity 3D world building software and was displayed using an Oculus Rift DK2 head-mounted display (HMD) device, with head tracking allowing them to see 3D computer-generated environments (where they find themselves in an animated computer-generated Ocean shore, within a Mountain area, and sitting on sandy reefs and watching the Sky) while listening to an instructor's recorded voice using headphones. Participants were asked to sit while practicing, and instructions were only provided through audio guidance. Visuals and audios were combined and presented as a multisensory experience using Unity3D software. In virtual world, participants were sitting toward the main scenery (e.g., Mountain), and they could turn their heads to see changing environment around central landscape (Figs 1-3). No interaction was designed in virtual environment.

Measures

For evaluating participants' background information, some items were included in a questionnaire: age, gender, job, education as well as, hours of using TV, playing video games, VR previous experiences, background knowledge about movie or animation, history of meditation and frequency of meditation practice during last month, and fear of height (acrophobia) and sea.

VR Experience Questionnaire

Six items were extracted from existing tools assessing sense of presence in virtual environments (e.g., (Baños et al., 2000)). A subset of items was chosen to keep experiment duration reasonable. This scale was only based on participants' personal assessments of their experience in VR. After completing meditation session, participants completed an 8-point Likert questionnaire (0-7) where their experience was evaluated in terms of the following dimensions: (a) spatial presence, (b) involvement, (c) mental immersion, (d) satisfaction, (e) perceived relaxing experience, (f) attention and attraction (Appendix I). Participants completed the questionnaire following immersion in a virtual version of each of three practices.

Integrative Self-Knowledge Scale

ISK (α=0.84, M=41.65, SD=9.66) includes 12 items recording individuals̓ efforts to develop past, present, and desired future self-experience into a meaningful whole (Ghorbani, Watson, & Hargis, 2008). For example, "If necessary, I can reflect on myself and clearly understand feelings and attitudes underlying my past behaviors." Responses were scored on a 5-point Likert scale ranging from 1 (largely untrue) to 5 (largely true). This scale has been shown to have good psychometric properties (Ghorbani et al., 2008).

Multidimensional Assessment of Interoceptive Awareness (MAIA)

MAIA is a tool used for evaluating eight dimensions of interoceptive awareness. This scale contains 32 items rated on the 6-point Likert scale, ranging from zero (never) to 5 (always) and higher scores show more interoceptive awareness. Its validity and reliability were confirmed in an English version (Mehling et al., 2012). Five specific dimensions of MAIA were included in analyses: not distracting (ND, tendency to not distracting and ignoring unpleasant senses), not worrying (NW, tendency to not worrying or not experiencing emotional distress facing pain or unpleasant senses), attention regulation (AR, ability to control and keep focusing on senses), listening to body (LB, dynamically paying attention to body to get insights), and trusting (TR, experiencing a safe and reliable body). These dimensions were selected because they had the most powerful psychometric properties in the Persian version of MAIA (Abbasi et al., 2018).

Mindful Attention and Awareness Scale (MAAS)

MAAS is a 15-item scale and has been widely employed in assessment of mindfulness. Responses are scored on a 6-point Likert scale ranging from 1 (almost always) to 6 (almost never). This scale has been shown to have acceptable psychometric properties (Brown & Ryan, 2003).

Spielberger State-Trait Anxiety Inventory (STAI)

This standardized scale was developed by Spielberger (1970) and is one of the most frequently used measures of anxiety. It has been shown to have good psychometric properties. STAI consists of 40 items measuring state (20 items) and trait (20 items) anxiety. Here, state anxiety subscale was used.

Psychophysiological Measures

Psychophysiological response data (HRV and RR) were recorded during each VR practice using dual-modality encoding system of biofeedback unit and BioGraph Infiniti ver.4.5 software (Procomp; Thought Technology Ltd., Quebec, Canada).

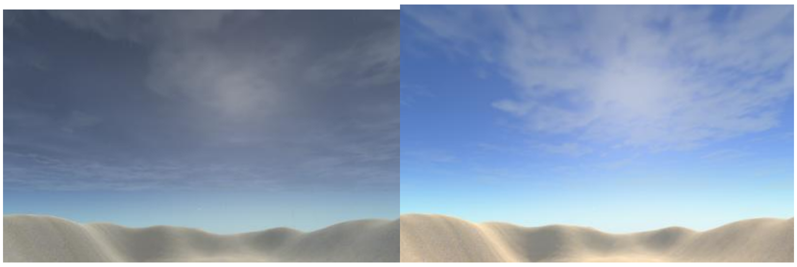

Figure 1. Sky meditation snapshots

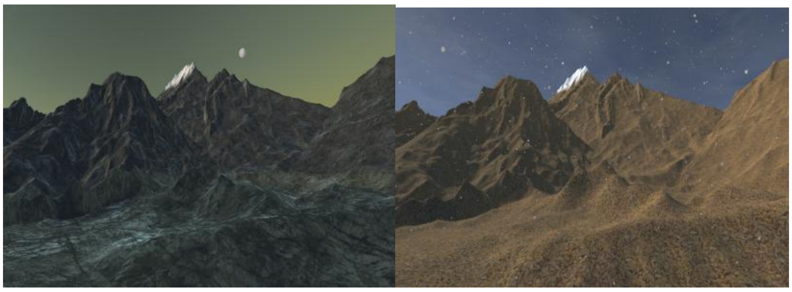

Figure 2. Mountain meditation snapshots

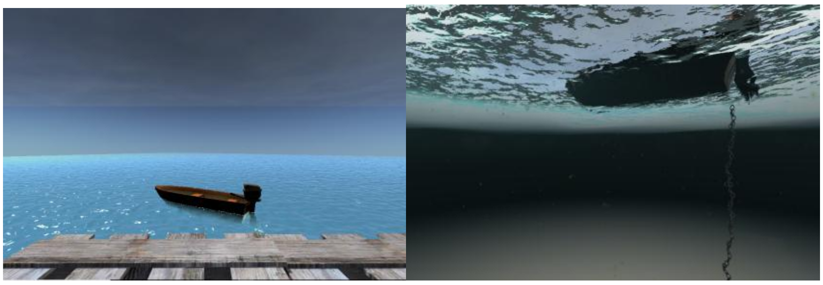

Figure 3. Ocean meditation snapshots

Procedure

Participants entered the lab and were provided with written information about purpose and methodology of the study and then, they filled out consent form. System features were explained to them and they got familiar with it using a demo. Also, they completed basic information form and studied questionnaires. Baseline physiological assessments including HRV and RR were recorded for each participant during completion of these questionnaires. Completing the questionnaires lasted about 15-20 minutes. For assessing changes in state anxiety, STAI test was used both before and after the experiment. Each meditation practice lasted about10 minutes. Three VR environments were randomly presented. After this experiment, electrodes were removed, and participants were appreciated for their collaboration.

Data Analysis

All statistical analyses were conducted using SPSS ver. 22 software (SPSS Inc., Chicago, IL). Paired-Samples t-test and Repeated-Measures ANOVA were employed to address differences in interval target variables, and Friedman test was used to test differences between ratings of each practice (two-tailed statistical analysis, $p<.05$). Also, Pearson correlation coefficient was employed for investigating the association between physiological indices and scores of mindfulness-related self-reports.

Results

Changes in Physiological Indices

HRV and RR recordings were visually evaluated for any artifacts. All files were shown to have usable data. Then, changes in HR, HRV-related data, and RR were averaged across baseline, Ocean, Sky, and Mountain practices. Table 1 shows means and standard deviations of physiological indices for baseline and during every three practices.

To test for specific impact of each practice in inducing physiological and psychological calmness, a series of within-subject contrasts were conducted. Contrasts were analyzed through F tests to determine significant changes in HF-HRV, RR, HR, and LF/HF HRV ratio from baseline through each practice. A significant difference was found between four conditions (baseline and three equanimity practices) in all of the above indices: HF-HRV ($F(3,219) = 7.71$, $p<.0001$), HR ($F(3,222) = 82.45$, $p<0.0001$), LF / HF HRV ratio ($F(3, 219) = 3.07$, $p=.02$), and RR ($F(3,222) = 7.34$, $p<.0001$). Post-hoc tests were run to confirm differences between the variables.

HR Changes

Results of post-hoc tests using Bonferroni correction revealed that HR, corresponding to better relaxation was reduced from baseline by an average of 6.42 (beats per minute, bpm) through

Ocean (p<.0001), by 5.83 (bpm) during Sky and by 5.50 (bpm) during mountain practice (p<.0001).

HRV

HF-HRV

This index of parasympathetic activity was improved relative to baseline, during exposure to equanimity practices. It was respectively higher than baseline for Ocean (mean difference=219.39, p<.0001), Mountain (mean difference=103.85, p=.009), and Sky (mean difference= 89.82, p<.01) practices.

LF/HF HRV Ratio

A greater mean drop was observed in LF-HRV (sympathetic) relative to HF-HRV (parasympathetic activity) in Ocean (mean difference=.31, p<.05) and Sky (mean difference=.30, p=.07) practices compared to baseline LF/HF-HRV ratio. However, this ratio showed no difference for Mountain practice compared to baseline ratio (p=.50) .Ocean and Sky practices were respectively shown to influence sympathovagal balance as indicated by LF/HF HRV ratio (von Rosenberg et al., 2017).

Changes in RR during Practices

Practicing equanimity caused a significant decrease in RR (breath per minute or br/min), as an index of parasympathetic activity, compared to baseline rates. The maximum effect was respectively observed after exposure to Ocean (br/min mean difference=1.72, p<.0001), Sky (br/min mean difference=.84, p<.01), and Mountain (br/min mean difference=.60, p<.03) practices.

Self-Report Measures

Mean and standard deviation of self-reported measures are shown in Table 1. Bivariate correlations were carried out between mindfulness-related capacities and changes in physiological reactivity scores from baseline through mindfulness practices to see how changes in physiological indices induced by practices are related to mindfulness-related capacities (signified by MAAS, ISK, and MAIA). For testing the hypothesis stating that higher levels of mindfulness-related capacities are positively associated with the increased parasympathetic indices and negatively with sympathetic as well as RR changes during each practice, a series of bivariate correlations were executed. Studying the association between MAAS and physiological changes during each practice showed that MAAS was positively correlated with HF-HRV changes during Ocean practice [r (75) = .32, p<.01]. Also, integrative self-knowledge capacity was positively correlated with changes in HF index during Ocean practice [r (75) = .23, p<.05] and ISK was negatively correlated with LF-HRV (sympathetic activity) relative to HF-HRV (parasympathetic activity) during Mountain practice [r (75) = -.25, p<.05]. Regarding assessing the effect of embodied presence and involvement in VR environment, five specific dimensions of MAIA were also included in analyses: ND, NW, AR, LB, and TR. Higher scores on ND were correlated with changes in LF/HF HRV ratio scores in Ocean [r (75) = -.23, p<.05] and Sky practices [r (75) = -.25, p<.05]. Higher levels of ND were correlated with lower change scores of RR [r (75) = -.23, p<.05] in Sky practice. Higher level of LB was related to higher HF in Ocean practice [r (75) = .22, p<.05], indicating that participants who are able to monitor and regulate their psychological and physical experiences are more likely to benefit from self-regulatory and equanimity trainings.

Table 1. Means, standard deviations, and ranges of physiological and self-report measures

	ISK	MAAS	ND	NW	AR	LB	TR	BASELINE HR	BASELINE HF	BASELINE RR	BASELINE LF/HF	OCEAN HR	OCEAN-HF	OCEAN RR	OCEAN LF/HF	SKY HR	SKY HF	SKY RR	SKY LF/HF	MOUNTA IN HR	MOUNTA IN HF	MOUNTA IN RR	MOUNTA IN LF/HF
MEAN	44.67	63.31	2.4	2.16	2.59	2.38	2.71	91.28	301.1	14.90	1.90	84.74	378.8	13.73	1.56	85.25	252.61	14.06	1.57	85.60	254.61	14.29	2.03
SD	8.16	9.32	.84	.92	.89	.55	1.17	12.04	422.4	1.64	1.49	10.84	610.05	2.29	1.42	11.45	291.95	2.50	1.21	10.59	333.62	2.32	2.11
RANGE	25-60	32-82	.67-4	.33-4.57	0-4.57	0-4	0-5	65.11-122.67	4.43-3283.2	10.88-18.11	.37-7.64	54.15-119.47	13.17-3404.80	7.96-17.90	.07-9.19	61.53-122.2	2.84-1638.91	6.95-19.46	.11-5.18	63.90-121.6	3.22-1979.3	8.51-17.57	.12-13.24

ISK= Integrative Self-Knowledge Scale; MAAS= Mindfulness Attention and Awareness Scale; MAIA= Multidimensional Assessment of Interoceptive Awareness; ND= Not Distracting; NW= Not Worrying; AR= Attention Regulation; LB= Listening to Body; TR= Trusting

Subjective Experience

The data extracted from 6 items were considered as ordinal, and Mann-Whitney U tests were employed to find differences in scores between the three practices. Fig. 4 shows distribution of ratings across the questionnaire items for each practice and Table 2 illustrates corresponding mean ranks and medians. One at a time, each outcome measure was considered as dependent variable. The comparisons using Mann-Whitney U tests showed significant differences between practices:

Spatial Presence

A significant difference was found in the level of the induced sense of presence between three practices (*Chi square= 10.77, p=.005*). Post-hoc comparisons showed higher levels of sense of presence in Ocean compared to Sky practice (z= -2.53, p=.01), and Mountain compared to Sky practice (z= -2.53, p=.01). But the level of sense of presence induced by Ocean and Mountain practices was not statistically different (z= -.18, p=.85).

Involvement

Three practices were also different in level of involvement experienced by the users when exposed to the practices (*Chi square=6.27, p=.043*) so that, more involvement belonged to Mountain practice than Sky practice (z=-2.29, p=.02). No significant difference was found in this variable between Mountain and Ocean practices (z= -1.53, p=.12). Furthermore, Ocean was not notably different from Sky practice regarding level of experienced involvement (z= -.81, p=.41)

Mental Immersion

The users rated the practices differently regarding level of induced mental immersion (*Chi square=18.86, p= .0001*). The differences were in favor of Ocean practice compared to Sky (z= -4.38, p=.0001) and Mountain practices (z= -1.70, p=0.08). Also, more immersion belonged to Mountain practice than Sky practice (z= -2.96, p=.003).

Satisfaction

Users' level of satisfaction with the practices was not similar (*Chi square=16.66, p=.0001*). They had more satisfying experience with Ocean (z=-3.15, p=.002) and Mountain (z= -2.40, p=.01) practices compared to Sky practice. However, Ocean and Mountain practices were not different regarding satisfaction ratings (z=-1.04, p=.29)

Perceived Relaxing Experience

Meditation in the three environments induced different levels of relaxation (*Chi square=11.01, p=.004)*. Participants perceived the Ocean (z=-1.98, p=.047) and Mountain (-3.17, p=.001) practices more comforting than Sky one. Also, no differences (z=-.95, p=.34) were found between Ocean and Mountain practices regarding level of induced relaxation.

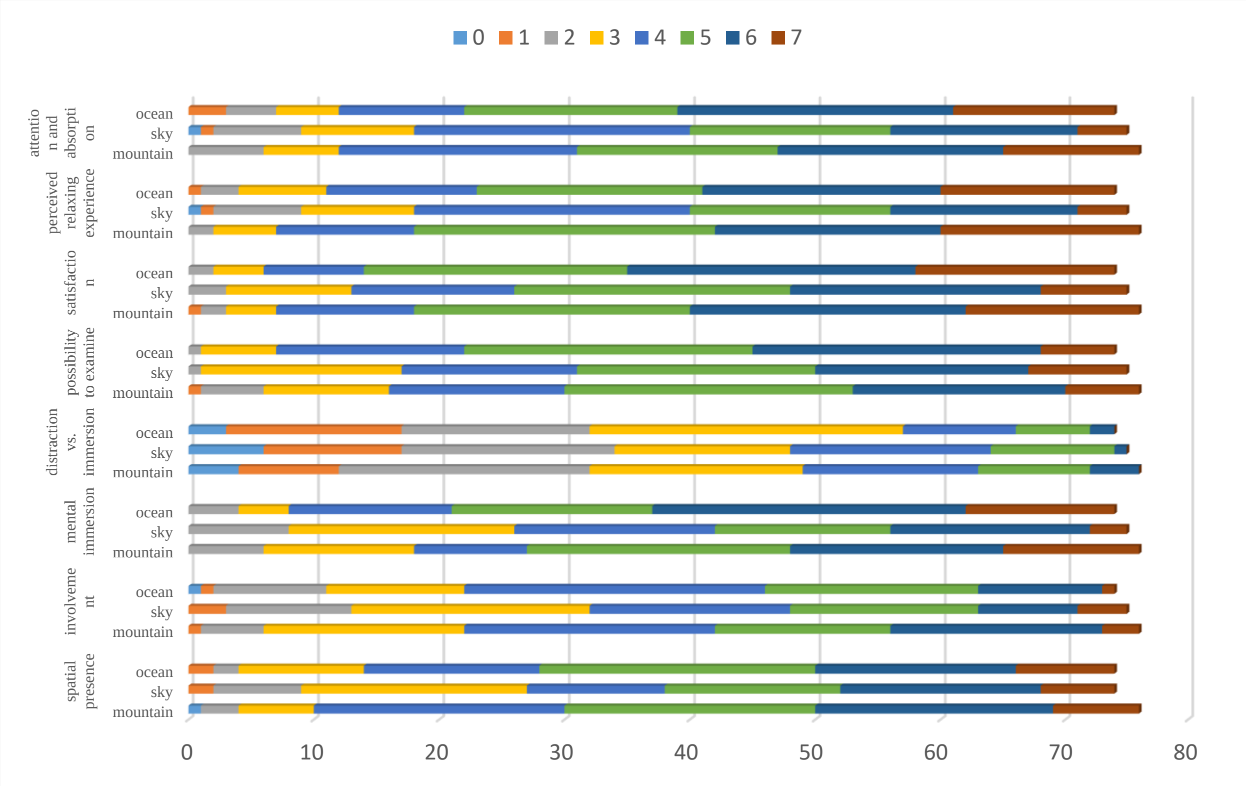

Figure 4. Distribution of self-ratings for practices

Attention and Absorption

Different levels of excitement were produced in the environments (*Chi square= 19.98, p=.0001*). Ocean (z= -3.04, p=-002) and Mountain practices (z= -2.62, p=.009) were more helpful in drawing attention and inducing attraction compared to Sky practice, but they were not rated differently in this variable (z= -.99, p=.31).

Table 2. Mean ranks and medians corresponding to each item of self-ratings for VR practices

Self-rating Items of experience with VR practices	Mean ranks			Medians		
	Ocean	Sky	Mountain	Ocean	Sky	Mountain
1. To what extent did you experience a sense of being there inside the environment you saw (spatial presence)?	2.14	1.72	2.14	5	4	5
2. How much did your experiences in the virtual environment seem consistent with your real-world experiences (involvement)?	1.97	1.83	2.20	4	4	4
3. How involved were you in the virtual environment experience (mental immersion)?	2.30	1.66	2.04	5.50	4	5
4. To what extent did the virtual experience seem satisfying to you (satisfaction)?	2.25	1.69	2.06	6	5	5
5. How relaxing was the experience (perceived relaxing experience)?	2.09	1.74	2.18	5	5	5
6. How exciting was the experience (attention and absorption)?	2.24	1.64	2.12	5	4	5

Change in Perceived State Anxiety after Practices

General changes in state anxiety levels were also studied before and after presenting three practices using Paired-Samples t-test. The results showed a significant reduction (t (74) =7.40, p<.0001) in self-reported assessment of state anxiety reflected in STAI.

Discussion and Conclusion

Herein, brief and accessible forms of equanimity training were introduced and studied in VR technology to make training available for novice users. The first set of analyses showed impact of practices in inducing physiological and psychological calmness. In the second set of analyses, changes in psychophysiological indices were shown to be related to the users' mindfulness-related capacities, assessed by MAAS, ISK, and MAIA scales. Investigating comparative satisfaction with three practices, represented in users' ratings of their sense of presence finally showed superiority of Ocean practice over Mountain and Sky practices in general .

Taking a look at the nature of each practice can be helpful to explain comparison results. All the three practices help a person to develop the attitude of welcoming pleasant experiences without clinging, and welcoming unpleasant experiences without turning away as well as nurturing the capacity to step into distress with openness and spaciousness. Ocean and Mountain practices focus on acceptance and equanimity in the middle of physical, psychological, or emotional hardships. Therefore, during these practices, a person can find himself closely dealing with difficulties. However, in Sky practice, the person's mind and its turbulence occur far from himself and there is a distance between the person and changes occurring in the sky. Therefore, this practice allows suffering to rise from a distant place and then, let it pass. In other words, Sky practice allows for a separation between person and experienced instability of physical and mental states. Although, this distancing shows to be effective in reducing attachment to contents of the mind (instructing that thoughts come and go like clouds floating through sky) but it may not train a person for engaging with unpleasant experiences without turning away and keeping his equanimity amidst changing emotional and external circumstances. Also, in Sky practice, one may be trained to approach discomfort with openness as the sky is wide and spacious to include a range of pleasant and unpleasant experiences. Gazing up at sky helps him to face the problems with a sense of spaciousness and greater perspective (Coleman, 2010) .

Ocean practice, as a practice for intimately engaging with difficult emotions and painful situations can enhance a person's capacity to tolerate, embrace, and accept difficult experiences in their true form, promoting stability in the middle of changing (internal and external) circumstances. In ocean metaphor, chaos and difficulties of life are likened to waves and storms in the ocean. We have no control over these waves and life stressors. But, we can go underneath of these surface challenges and to the depth where water is calmer and rest in there. While, we sit beneath the waves, we can clearly see and feel challenges and emotional turmoil with courage. Also, a practicing person has a wide-angle lens enabling him to see challenges with greater objectivity, equanimity, and from a centered, deep inner place (S. Shapiro, Siegel, & Neff, 2018) .

In Mountain practice, a person can embody a central and solid stillness and groundedness in face of constant changes in his own life over time. By becoming a mountain, one can connect with its strong, solid, and stable nature and embrace them. As an example of instructions in Mountain practice, we have: "I am sitting cross-legged on the floor so that, my body looks and feels mostly mountain-like, inside and out…simultaneously, embodying universal qualities of "mountain-ness" transcending particular shape and form". Mountain practice seems to make practicing person more engaged with challenges compared to Sky practice that is less engaging regarding face-to-face dealing with challenges. This fact can also be applied to Ocean practice as observed in Kabat-Zinn's instruction (Kabat-Zinn, 2009) for Lake or Ocean practice: "…allow yourself to become one with the lake while lying down on your back ."

Our findings demonstrated that equanimity practice using VR was associated with attenuated involvement of sympathetic nervous system, indicated by LF/HF HRV ratio and HR indices (Berntson, Quigley, & Lozano, 2007). These practices were also associated with stronger engagement of parasympathetic responding, shown in HF-HRV reactivity and RR. Parasympathetic system is responsible for downregulation of bodily tension during stressful events. HF, an index of parasympathetic activity is also considered as a marker of equanimity (Desbordes et al., 2015). Practicing equanimity was shown to enhance stronger involvement of parasympathetic system, reflected in the users' self-ratings of state anxiety.

These findings were supported by convergent validity of self-report measures and psychophysiological indices. It was also hypothesized that the individuals' awareness of physical and psychological experiences in the present moment would be related to enhanced parasympathetic response and reductions in level of sympathetic activity during equanimity practice. Findings showed that users with higher capacity of interoceptive awareness, mindfulness, and integrative self-knowledge more efficiently downregulate autonomic activity using equanimity practices, meaning that individuals who are connected with their immediate internal experiences would more likely show balanced autonomic activity during the practices .

Participant's integrative self-knowledge was shown to be related to a lower sympathetic activity during Mountain practice. Also, MAAS measuring attentional aspect of mindfulness with an emphasis on openness to experiences was related to more physiological calmness during Ocean practice. The relationship between ISK and physiological changes during Mountain practice can be discussed by considering the content of practice. Mountain practice had an abstract and metaphor-laden content (e.g., standing grounded, still, and centered in face of joy, sorrow, and life challenges like a mountain facing changes like storms, wind, darkness, heat, and rain) and attuning with it may need more meta-cognitive insight than the other two practices. On the other hand, MAAS scores were associated with physiological calmness during Ocean practice. As, Ocean practice emphasized openness to experiences and introduced a simple and objective content, which may need higher levels of open and receptive attention and awareness rather than higher-order levels of cognition and reflection .

Interoceptive awareness considered as a potential mechanism for current mindfulness interventions involves being aware of (intense) physical sensations and keeping stillness during this experience (Mehling et al., 2009). For example, LB dimension of MAIA involves the capacity to regulate attention to physical sensations. This capacity was related to high levels of parasympathetic activity in Ocean practice. Detecting signals from physical sensations provides a person with essential feedbacks and non-judgmental awareness from moment to moment and encourages maintaining self-regulation during equanimity practice. According to results, interoceptive awareness was associated with lower levels of physiological stress. The association between interoceptive awareness dimensions and physiological calmness during equanimity training supports the claim that interoceptive awareness can help a person to greatly benefit from practicing equanimity. Overall, ISK and mindfulness capacity together with detecting physical signals and regulating mind and body based on these cues may increase impact of equanimity practices in VR .

Feedbacks after completion of VR practices showed that, participants experienced the same levels of "satisfaction," "relaxation," "attention" (attraction), and "spatial presence" during Ocean and Mountain practices. Level of “mental immersion” was higher in Ocean practice than Mountain practice. However, Mountain practice was the most “involving” practice among three practices. The weakest self-rated experience with VR practices was related to Sky practice. As discussed above, the nature of each practice can explain the results. Finally, based on STAI scores, anxiety level of participants was positively influenced by presenting three practices and was attenuated after finishing three practices .

This study also calls for further research to investigate and design new VR-based approaches for cultivating equanimity. Our results confirmed that training equanimity through VR could be useful in balancing psychological and physiological experiences. Besides, it was found that, in VR-based equanimity practice, awareness of psychological and somatic events is associated with better physiological indices of equanimity. Hence, it can be suggested that integrating the instructions related to mindfulness and interoceptive awareness can enhance equanimity training outcomes .

Results of the current study should be considered along with its limitations. First, the current study only included university students and the results cannot be generalized to other populations. For strengthening the results, it would be recommended to consider between-condition designs. In our study, each meditation practice lasted about 10 minutes, this time may not be enough to generate a good immersion in VR; thus in future research, it is suggested to extend the duration of each immersion and that each one does not exceed 30 minutes. It is suggested to make the immersions in different sessions in order to avoid negative effects regarding using VR (cybersickness). VR-versions of equanimity practices can also be compared with teacher-instructed equanimity practices in future studies. This can help us to understand whether this system can complement existing mindfulness trainings or not.

Declarations

Author Contributions

All authors contributed actively to the conception, design, and execution of the research.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Acknowledgements

We are deeply grateful to Professor Javad Hatami, Department of Psychology, University of Tehran, for generously providing access to the Virtual Reality laboratory, and for his valuable guidance in the design, implementation, and writing of this study. His support and insights significantly enriched the quality of this work.

Ethical considerations

All procedures performed in studies involving human participants were in accordance with the ethical standards of University of Tehran research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Ethic approval has been obtained before conducting the research.

Funding

The authors received no financial support for the research, authorship, and publication of this article.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

References

Ayduk, Ö., & Kross, E. (2008). Enhancing the pace of recovery: Self-distanced analysis of negative experiences reduces blood pressure reactivity. *Psychological science, 19*(3), 229-231.

Ayduk, Ö., & Kross, E. (2010). From a distance: implications of spontaneous self-distancing for adaptive self-reflection. *Journal of personality and social psychology*, *98*(5), 809.

Baños, R. M., Botella, C., Garcia-Palacios, A., Villa, H., Perpiñá, C., & Alcaniz, M. (2000). Presence and reality judgment in virtual environments: a unitary construct? *CyberPsychology & Behavior*, *3*(3), 327-335.

Baños, R. M., Botella, C., Garcia-Palacios, A., Villa, H., Perpiñá, C., & Gallardo, M. (1999). Psychological variables and reality judgment in virtual environments: the roles of absorption and dissociation. *CyberPsychology & Behavior*, *2*(2), 143-148.

Berntson, G. G., Quigley, K. S., & Lozano, D. (2007). Cardiovascular psychophysiology. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (Vol. 3, pp. 182-210). New York: Cambridge University Press.

Bokenkamp, S. (2005). Daoism: An overview In L. Jones, M. Eliade, & C. J. Adams (Eds.), *Encyclopedia of religion* (2nd ed., pp. 2176–2192). Detroit, MI: MacMillan Reference USA.

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: mindfulness and its role in psychological well-being. *Journal of personality and social psychology, 84*(4), 822.

Coleman, M. (2010). *Awake in the wild: Mindfulness in nature as a path of self-discovery*: New World Library.

Desbordes, G., Gard, T., Hoge, E. A., Hölzel, B. K., Kerr, C., Lazar, S. W., . . . Vago, D. R. (2015). Moving beyond mindfulness: defining equanimity as an outcome measure in meditation and contemplative research. *Mindfulness, 6*(2), 356-372.

Ghorbani, N., Watson, P., & Hargis, M. B. (2008). Integrative Self-Knowledge Scale: Correlations and incremental validity of a cross-cultural measure developed in Iran and the United States. *The Journal of Psychology, 142*(4), 395-412.

Goldstein, J., & Kornfield, J. (2001). *Seeking the heart of wisdom: The path of insight meditation*. Boston: Shambhala Publications.

Harvey, P. (2012). *An introduction to Buddhism: Teachings, history and practices*. Cambridge, UK: Cambridge University Press.

Kabat-Zinn, J. (1994). *Wherever you go, there you are: Mindfulness meditation in everyday life*. New York: Hyperion.

Kabat-Zinn, J. (2009). *Wherever you go, there you are: Mindfulness meditation in everyday life*: Hachette Books.

Kosunen, I., Salminen, M., Järvelä, S., Ruonala, A., Ravaja, N., & Jacucci, G. (2016). *RelaWorld: neuroadaptive and immersive virtual reality meditation system.* Paper presented at the Proceedings of the 21st International Conference on Intelligent User Interfaces.

Mehling, W. E., Gopisetty, V., Daubenmier, J., Price, C. J., Hecht, F. M., & Stewart, A. (2009). Body awareness: construct and self-report measures. *PloS one*, *4*(5), e5614.

Mehling, W. E., Price, C., Daubenmier, J. J., Acree, M., Bartmess, E., & Stewart, A. (2012). The multidimensional assessment of interoceptive awareness (MAIA). *PloS one, 7*(11), e48230.

Parsons, C. E., Crane, C., Parsons, L. J., Fjorback, L. O., & Kuyken, W. (2017). Home practice in Mindfulness-Based Cognitive Therapy and Mindfulness-Based Stress Reduction: A systematic review and meta-analysis of participants' mindfulness practice and its association with outcomes. *Behaviour research and therapy, 95*, 29-41.

Pollak, S. M., Pedulla, T., & Siegel, R. D. (2014). *Sitting together: Essential skills for mindfulness-based psychotherapy*. New York, NY: Guilford Publications.

Riva, G., Botella, C., Baños, R., Mantovani, F., García-Palacios, A., Quero, S., . . . Dakanalis, A. (2015). Presence-inducing media for mental health applications. In M. Lombard, F. Biocca, J. Freeman, W. IJsselsteijn, & R. Schaevitz (Eds.), *Immersed in media* (pp. 283-332): Springer.

Seol, E., Min, S., Seo, S., Jung, S., Lee, Y., Lee, J., . . . Cho, C.-H. (2017). *" Drop the beat" virtual reality based mindfulness and cognitive behavioral therapy for panic disorder---a pilot study*. Paper presented at the Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology.

Shapiro, S., Siegel, R., & Neff, K. D. (2018). Paradoxes of mindfulness. *Mindfulness, 9*(6), 1693-1701.

Shapiro, S. L., Jazaieri, H., & de Sousa, S. (2009). Meditation and Positive Psychology. In C. R. Snyder & S. J. Lopez (Eds.), *The Oxford Handbook of Positive Psychology, 3rd Edition* (pp. 601-610). New York, NY: Oxford University Press.

Shaw, C. D., Gromala, D., & Seay, A. F. (2007). The meditation chamber: Enacting autonomic senses. *Proc. of ENACTIVE/07*.

Sliwinski, J., Katsikitis, M., & Jones, C. M. (2017). A review of interactive technologies as support tools for the cultivation of mindfulness. *Mindfulness, 8*(5), 1150-1159.

Stellar, J. E., Manzo, V. M., Kraus, M. W., & Keltner, D. (2012). Class and compassion: Socioeconomic factors predict responses to suffering. *Emotion, 12*(3), 449.

Vincelli, F., Molinari, E., & Riva, G. (2001). Virtual reality as clinical tool: immersion and three-dimensionality in the relationship between patient and therapist. *Studies in Health technology and Informatics, 81*, 551-553.

von Rosenberg, W., Chanwimalueang, T., Adjei, T., Jaffer, U., Goverdovsky, V., & Mandic, D. P. (2017). Resolving ambiguities in the LF/HF ratio: LF-HF scatter plots for the categorization of mental and physical stress from HRV. *Frontiers in physiology, 8*, 360.

Wallace, B. A., & Shapiro, S. L. (2006). Mental balance and well-being: building bridges between Buddhism and Western psychology. *American Psychologist, 61*(7), 690.

Appendix I: Users' self-evaluation of their experience with VR-based meditation practices

1. To what extent did you experience a sense of presence inside the environment you saw (spatial presence)?

0	1	2	3	4	5	6	7

Not at all   Very Much

2. How much did your experiences in the virtual environment seem to be consistent with your real-world experiences (involvement)?

0	1	2	3	4	5	6	7

Not Consistent   Very Consistent

3. To what extent were you involved in the virtual environment experience (mental immersion)?

0	1	2	3	4	5	6	7

Not Involved   Completely Engrossed

4. To what extent did the virtual experience seem satisfying to you (satisfaction)?

0	1	2	3	4	5	6	7

Not exciting   Very much exciting

5. How relaxing was the experience (perceived relaxing experience)?

0	1	2	3	4	5	6	7

Not relaxing   Very much relaxing

6. How exciting was the experience (attention and attraction)?

0	1	2	3	4	5	6	7

Not exciting   Very much exciting