Virtual Reality (2025) 29:68
https://doi.org/10.1007/s10055-025-01138-9

ORIGINAL ARTICLE

Levitation experience in virtual reality

Mounia Ziat[1] · Rishi Jhunjhunwala[1] · Adwait Gharat[1] · Yo Deshpande[1] · Roope Raisamo[2]

Received: 7 October 2023 / Accepted: 26 March 2025 / Published online: 10 April 2025

Abstract
We investigated the effects of combining VR-guided meditation with out-of-body experiences, such as levitation, on embodiment and mindfulness practices. Participants engaged in a self-view (video feedback) meditation session followed by a levitation phase in a VR environment. We observed a significant increase in participants' EDA responses during the levitation phase. The results were influenced by several factors, including the duration of the meditation, the length of the levitation phase, and participants' subjective experiences. Participants who reported higher scores on the physical levitation scale exhibited an open and curious attitude, accepting the experience without becoming overly absorbed. In contrast, individuals with the capacity to observe and distance themselves from their feelings, emotions, and experiences were less inclined to report a virtual levitation experience.

Keywords Levitation · VR-guided meditation · Electrodermal activity · Mindfulness

1 Introduction

Illusions are compelling perceptual phenomena that deceive the brain, leaving us puzzled and questioning the reality of our senses. Extensive research has explored various illusions in the visual, auditory, and tactile domains (Warren and Warren 1970; Coren and Girgus 2020; Ziat et al. 2014; Ziat and Raisamo 2017), enriching our understanding of these captivating perceptual experiences. In this study, we focus specifically on two intriguing illusions: vection and out-of-body experiences (OBEs). Although distinct, they share overlapping perceptual experiences. Vection primarily involves the illusion of self-motion in the absence of actual movement, while OBEs involve individuals perceiving themselves outside their physical body. Of particular interest for this work is levitation, a concept often associated with meditation and described as a rising body in the air. Levitation can be seen as an intersection of these two illusions when framed within a VR context. In a controlled environment, VR offers the potential to induce a sensation of levitation, drawing parallels with both vection (the sensation of moving upward) and OBEs (the detachment from one's physical body).

Mindfulness meditation, rooted in ancient practices, often examines experiences that transcend the usual bounds of physical perception. While there is no scientific evidence supporting the occurrence of actual physical levitation, these sensations can be understood within the framework of altered states of consciousness, similar to those observed in hypnosis and mindfulness practices. Traditional beliefs describe extraordinary abilities, known as Siddhis, attributed to advanced yogis. One such Siddhi, Laghima, is described as the ability to become lighter than air (Jacobsen 2011). Although these accounts are rooted in ancient traditions and lack empirical verification, the sensation of 'rising' or 'floating' reported by many practitioners can be interpreted as a mental sensation of levitation. In the context of this study, such sensations are explored as subjective experiences with profound psychological implications and connections to body ownership illusions. These altered states provide an intriguing overlap for understanding the potential of VR-mediated experiences in simulating these sensations.

Virtual reality (VR) emerges as a groundbreaking tool. Its immersive nature not only simulates experiences but can also evoke genuine physiological and psychological

Rishi Jhunjhunwala, Adwait Gharat, Yo Deshpande, and Roope Raisamo contributed equally to this work.

✉ Mounia Ziat
mziat@bentley.edu

[1] Bentley University, IDCC, Waltham 02451, USA

[2] Tampere University, Tampere, Finland

responses (Arpaia et al. 2022). Hence, in this study, we can explore how perception, sensation, and cognition collectively contribute to and enhance the holistic experience of a virtual body levitating within a VR environment. We conducted a VR-guided meditation session by combining the concept of levitation with an induced OBE, where participants observe their visual bodies from a location outside their physical body. During the session, participants observed a mirror-like self-view levitating in the VR environment, creating a vection sensation of their physical body moving upwards while their skin conductance was measured using Electrodermal Activity (EDA). EDA serves as a reliable indicator of physiological arousal (Dawson et al. 2007) and is a key physiological measurement tool that provides insights into the autonomic nervous system's responses to various stimuli, including those experienced in VR environments (for a full review, see (Ladakis et al. 2024)). Hence, fluctuations in EDA can provide insights into the participant's engagement and immersion levels. Previous studies have utilized EDA to measure responses during VR-mediated mindfulness sessions, demonstrating its efficacy in capturing real-time physiological responses to immersive experiences (Anderson 2017; Huang et al. 2020). In both studies, a decrease in skin conductance levels was observed at the end of the VR sessions, suggesting that VR mindfulness sessions help with relaxation and reduce stress. Additionally, previous OBE studies (Ehrsson et al. 2007; Ehrsson 2009; Braithwaite et al. 2017) have established a correlation between EDA and the intensity of the experience, making it a valid metric for our study.

Our primary objective for this work is to explore a novel paradigm of VR-guided meditation with a focus on levitation. Our secondary objective is to contribute to the existing literature on OBEs and introduce a new levitation illusion that can be enhanced using various modalities in the future. We seek to understand participants' physiological and psychological responses during such experiences and provide insights into the broader implications of VR-enhanced meditation practices. A growing body of research leverages virtual reality to investigate body ownership and VR-guided meditation (Andersen et al. 2017). The subsequent sections examine previous studies on both VR meditation and OBEs, which support the notion that immersive virtual reality environments can induce significant changes in consciousness.

1.1 VR investigations of OBEs

The term "out-of-body" experience was coined by parapsychologist George Nugent Merle Tyrrell (Tyrrell 2022) and popularized by broadcaster Robert Allan Monroe (Russell 2007) to describe hallucinations and near-death experiences. While OBEs are often associated with pathological conditions and brain lesions (Blanke et al. 2004), they have also been induced in experimental settings, focusing on full-body perceptions from external perspectives. In contrast, phenomena such as the rubber hand illusion (Botvinick and Cohen 1998) relate more directly to body-part ownership but share underlying mechanisms with OBEs, such as the integration of multisensory information to construct bodily self-consciousness (Olivé and Berthoz 2012). A commonly used paradigm involves stroking the skin with a brush to induce proprioceptive drift or elicit emotional responses. In these studies, participants observed a real-time representation of themselves or a view of the stroking brush as if they were positioned a few meters ahead of or behind their physical bodies. The illusion was strengthened by stroking areas such as the back or chest, leading participants to perceive their bodies in front of or behind their actual location (Ehrsson 2007; Lenggenhager et al. 2007). These experiments demonstrate the compelling nature of such illusions and their potential to alter states of consciousness.

A notable study by Lenggenhager et al. investigated an induced levitation illusion within the context of OBEs. In their research, the perception of self-localization was manipulated through visual-tactile integration. Participants were placed in a prone position and stroked on either their backs or chests while viewing a video of their body being stroked in real-time or with a slight delay, creating synchronous and asynchronous conditions, respectively. When participants experienced synchronous stroking on their chests, they reported a sensation of their self-localization drifting upwards, accompanied by a floating sensation reminiscent of the illusion of levitation or clinical OBE conditions where patients often report feeling detached from their physical bodies. This elevation was often associated with sensations of floating, highlighting a modulation of vestibular sensations, which are significant in OBEs (Lenggenhager et al. 2009).

With the advent of virtual reality, the possibilities for inducing and studying OBEs have expanded. VR allows for controlled environments where participants can experience more immersive and vivid OBEs, building on traditional methods and offering the potential for deeper insights into this phenomenon (see Mottelson et al. (2023) for a comprehensive review). In a recent study by Martial et al. (2023), the researchers focused on examining the EEG signatures associated with VR-induced OBEs. The participant's viewpoint was lifted, creating the illusion of their virtual body flying toward the ceiling. The study reported an increase in delta power and a decrease in alpha power relative to the experience, indicating a shift in brain activity during the OBE and consistent with prior research highlighting the involvement of delta activity in altered states of consciousness (Frohlich et al. 2021). This underscores the capacity of VR to simulate realistic and measurable OBEs.

Other research further supports the efficacy of VR in altering bodily self-consciousness. For instance, changes in body size (Normand et al. 2011) and body image (Murray and Fox 2005) have been shown to impact the strength of the illusion, demonstrating VR's potential in manipulating self-perception. Additionally, wearing a VR headset can shift self-location perception from the torso to the upper face when participants are asked to point at themselves (Van der Veer et al. 2018), highlighting how VR can alter fundamental aspects of bodily self-consciousness.

1.2 VR-guided meditation

Mindfulness and traditional meditation techniques have been extensively studied and practiced for centuries, demonstrating numerous benefits in stress reduction (Astin 1997), prevention of depression relapse (Bieling 2012), pain management (Syrjala 2014), and overall promotion of health and well-being (Galante et al. 2014; Chandrasiri et al. 2020). Traditional meditation often involves finding a quiet space, closing one's eyes, and focusing on the breath. In contrast, VR-guided meditation introduces a novel approach where users are encouraged to keep their eyes open to fully immerse themselves in the simulated environment. These virtual settings, which may include serene mountains, soothing beaches, or relaxing forests, aim to enhance the yogi's sense of immersion and presence (Alyan 2021; Kim 2021; Manaf et al. 2021). VR meditation provides unique opportunities and advantages by minimizing external distractions and enabling the exploration of research paradigms that would otherwise be challenging to investigate, such as the specific focus on levitation in the study presented here.

There are already multiple existing VR-guided meditation programs designed to foster mindfulness and improve meditation practices. In particular, researchers have developed immersive VR-guided meditation paradigms aimed at assisting individuals with chronic pain to reduce and manage their pain effectively (Gromala et al. 2015; Venuturupalli 2019; Sarkar et al. 2022). Moreover, VR mindfulness has shown the potential to reduce anxiety symptoms (Tarrant et al. 2018), increase focus (Kaplan-Rakowski et al. 2021), and facilitate stress management (Weitzman 2021). Additionally, the benefits of VR in promoting mindfulness practices, enhancing the sense of presence, and improving overall well-being, positioning it as a promising therapeutic tool, have been demonstrated in various studies (Navarro-Haro 2017; Pascual et al. 2023). During the COVID-19 pandemic, VR-based mindfulness and art therapy were proposed to address the psychological impact and social exclusion caused by the emergency, highlighting the versatility of VR in therapeutic settings (Gatto et al. 2020).

While VR-guided meditation offers unique opportunities, it also comes with challenges. Ensuring the virtual environment aligns with individual preferences, mitigating potential VR-induced discomfort, and understanding the long-term effects of such meditation warrant further exploration. Moreover, further investigation is required to tailor VR-guided meditation programs to individual users' needs. For example, individuals with mild PTSD responded positively to VR-guided meditation compared to non-VR meditation. Nonetheless, the system was less effective for individuals with acute PTSD symptoms (Mistry 2020).

Longitudinal VR-guided mindfulness training offers a potential solution to understand the impact of these challenges by providing an immersive and controlled environment that enhances engagement and focus. Previous studies have demonstrated the effectiveness of regular mindfulness practice (eight weeks) in reducing stress levels within simulated VR environments (Crescentini et al. 2016) or through mindful gamification (Sliwinski et al. 2015). Additionally, the integration of adaptive VR meditation based on biofeedback shows promise in overcoming certain limitations. For instance, respiratory biofeedback has been shown to lower arousal during meditation (Tinga et al. 2019), while distinct changes in brain activity associated with VR-guided meditation have been observed in cancer patients (Fu 2021).

While traditional mindfulness practices are effective in reducing stress, VR environments offer unique benefits such as enhanced sensory immersion, personalized and novel experiences, increased user motivation, and a controlled environment (Arpaia et al. 2021; Barton et al. 2024). Studies have shown that VR-based mindfulness can significantly improve mood and reduce anxiety more effectively than audio-based meditation. For instance, a study found that VR mindfulness sessions led to higher feelings of relaxation and decreased stress levels among healthcare workers compared to audio-guided meditation (Tarrant et al. 2018). Similarly, a large decrease in anxiety scores of individuals experiencing homelessness was observed among the virtual reality meditation group compared to the web-based or image-based meditation groups (Chavez 2020), suggesting that VR environments help reduce external distractions and enhance the sense of presence, which in turn can improve adherence to mindfulness practices.

Only one study has investigated the concept of virtual levitation within the context of VR-guided meditation. During this study, participants were seated on a chair and instructed to engage in multiple 10-minute meditation sessions while their brain activity was monitored in real-time. Once they achieved a certain level of performance, they perceived the virtual environment moving upwards, creating an illusion of levitation. It is worth mentioning that participants did not visually perceive their body levitating; instead, they experienced a first-person view where the perception of upward movement resulted in deeper relaxation, an increased sense of presence, and heightened meditation levels (Kosunen et al. 2016).

2 Methods

2.1 Participants

The study involved thirty-six participants from Bentley University, consisting of 22 females and 14 males, who received a $15 gift card for their participation. The age range of the participants varied from 18 to 41, with a standard deviation of approximately 5.88. Prior to conducting the experiment, the study received approval from the Institutional Research Board (IRB) at Bentley University. The study was performed in accordance with the Declaration of Helsinki guidelines and regulations and informed consent was obtained from all participants.

2.2 Materials

2.2.1 Apparatus

An Electrodermal Activity (EDA) from Neulog with two dry electrodes was used throughout the experiment to measure skin conductance. The Neulog range of operation is from 0 to 10 μS with a 16-bit ADC and 100 samples per second (Flagler et al. 2020).

The virtual reality component of the study utilized the Oculus Quest VR headset, featuring a resolution of 1440×1600 and a refresh rate of 72 Hz. The headset provided an immersive experience with an 89° field of view and integrated stereo speakers for enhanced 3D audio. The VR environment, created in Unity 2021.3.21, depicted a serene outdoor setting with a beautiful Sakura tree in the background. The environment was constructed using a combination of Unity standard assets and carefully chosen assets from the Unity Store, specifically the Unity Fantasy Adventure Environment and Unity Sun Temple. The VR environment incorporated various audio and visual elements, such as relaxing music, the chirping of birds, and the sight of leaves gracefully drifting in the wind (see Fig. 2a). The background sound featured a harmonious blend of nature sounds recorded near a small river on the outskirts of Fukuoka, with chirping birds and the peaceful flow of the river.

The background music, "Morning Meditation," was selected from the TrackSonix playlist. Additionally, the sound of the wind was from an online recording of high wind gusts blowing through spruce trees on an exposed mountain ridge. The final audio track was composed using Adobe Premiere Pro and Unity's Audio Mixer (see a sample video in Supplementary Information).

A Canon 2500D camera was used to record a video of the participant. Participants' virtual image was positioned on a colorful mat in front of the tree. The virtual image comprised a 30-second video of the participant in the crossed-legged position looping continuously (see procedure for details).

During the meditation session, participants were accompanied by a soothing voice recorded specifically for this purpose. The recordings were made by one of the co-authors, who is an experienced mindfulness practitioner and regularly leads meditation sessions. The sessions varied in duration, lasting either 5, 10, or 15 min, with a brief silence of 10, 20, or 30 s (levitation phase), followed by a 15-second closing segment. The meditation session followed a general structure of five stages, as illustrated in Fig. 1 and described below:

1. Initially, participants were instructed to find a comfortable, upright sitting position with their eyes open.
2. Next, they were guided through breathing exercises.
3. Participants were then prompted to gradually scan their bodies and become aware of any sensations they experienced.

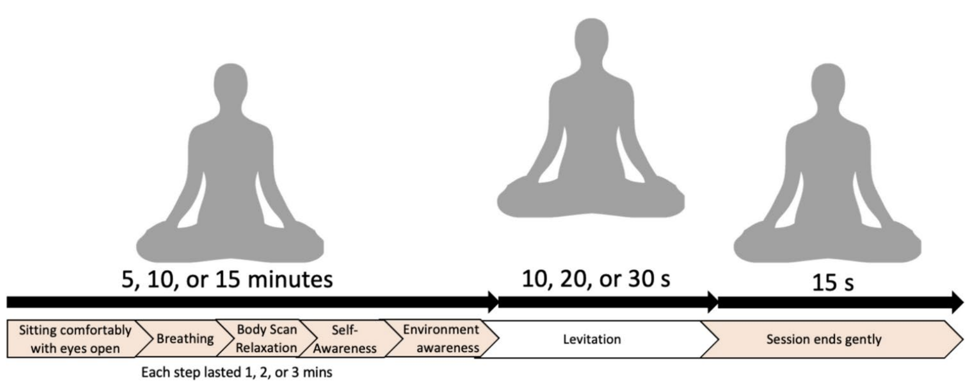

Fig. 1 The meditation session lasted 5, 10, or 15 min (1, 2, or 3 min for each stage, followed by a levitation phase of 10, 20, or 30 s to end with a 15-second phase to terminate the session gently

4. They were encouraged to observe any thoughts that arose and, when their mind wandered, to refocus their attention on their breathing.
5. Lastly, participants were directed to bring their attention to the environment (birds, winds, leaves, etc.).

The nine chosen conditions were designed to provide a comprehensive overview of participants' experiences across varying durations and intensities of VR-guided meditation and levitation. These conditions were informed by preliminary feedback and pilot testing, ensuring that the chosen parameters were both feasible and relevant.

2.2.2 Questionnaires

Participants were administered several questionnaires as part of the study. These included the Five Facet Mindfulness Questionnaire (FFMQ), the Toronto Mindfulness Questionnaire (TMS), the out-of-body-levitation experience (OBLE)- an adapted version of the OBE questionnaire, as well as additional questions relating to immersion and relaxation (see Supplementary Information for more details). These questionnaires were chosen based on their relevance to the study's objective. Given that meditation is an exercise in mindfulness, assessing participants' inherent (trait) and current (state) mindfulness levels can provide deeper insights into their experiences during the VR-guided meditation sessions.

The FFMQ is a 39-item "Trait-like" assessment of the enduring effects of meditative practice with a 5-point scale (Baer et al. 2006). It evaluates five key facets: 1) Observing: the ability to pay attention to bodily experiences or sensations; 2) Describing: skill in accurately describing one's feelings; 3) Mindful actions: the tendency to be aware of one's surroundings; 4) Non-judging: the inclination to refrain from labeling thoughts as good or bad; and 5) Non-reactive: the capacity to observe experiences, feelings, or emotions without immediately reacting to them.

The TMS is a 13-item scale of "state-like" experiences during meditation on a 5-point scale (Lau 2006). It consists of two factors: 1) Curiosity: reflecting an interest in one's experience without judgment, and 2) Decentering: considering thoughts and feelings as temporary and objective events in the mind rather than perceiving them as factual or descriptive of self. The OBE questionnaire (Lenggenhager et al. 2007, 2009), with scores from − 3 to 3, was specifically tailored for this study. We placed particular emphasis on two levitation-related questions: 1) Virtual Levitation: "It appeared (visually) as if the virtual body/ image were drifting upwards." and 2) Physical Levitation: "It felt as if my (real) body was drifting upwards." Finally, participants were asked two questions about the moments when they felt most immersed/relaxed and least immersed/relaxed and to provide any feedback.

2.3 Procedure

After signing the consent form, participants were invited to sit in a cross-legged position on a yoga mat with their backs and neck straight. This position, known as Shukhasana or Muktasana, is commonly used as a warm-up or finishing pose in yoga practice and is considered ideal for meditation. Participants were asked to take deep breaths while maintaining this posture, as a 30-second video of themselves was recorded. The camera was positioned approximately 1 m away, with a green screen background, to facilitate video extraction. The green screen was later removed using the ChromaKey tool shader in Unity.

During the video processing and integration into the VR environment, which took approximately 3–4 min, participants were invited to complete the FFMQ before the meditation session. EDA electrodes were attached to the first phalanx of the index and ring fingers on participants' left hands using Velcro straps. Once the video was incorporated into the VR environment, participants were asked to wear the VR headset while maintaining the same seated posture and engage in a guided meditation session. It is worth noting that participants were instructed to keep their eyes open throughout the entire VR experience.

Participants observed themselves in the VR environment seated in a cross-legged position on a mat as if looking into a mirror. At the end of the meditation practice, their virtual bodies briefly levitated before returning to their initial position. The guided meditation practice varied in duration, with 5, 10, or 15 min (M5, M10, and M15, respectively). The levitation phase occurred for either 10, 20, or 30 s (L10, L20, and L30), representing the time it took for the body to rise and return to its original position (see Fig. 2b). It resulted in nine distinct conditions (3 Meditation × 3 Levitation), with four participants randomly assigned to each condition. A 15-second end-of-session was included to facilitate a gentle exit for participants and to conclude their experience gradually. After removing the VR headset, participants were asked to complete the TMS, the OBE questionnaire, and other questions. They were also encouraged to provide any additional comments about their overall experience.

Data for EDA and questionnaires were collected from 36 participants in a between-subjects design. Participants were assigned to one of the nine conditions: three meditation durations (M5, M10, and M15) and three levitation durations (L10, L20, and L30). These conditions were designed to provide a comprehensive overview of participants' experiences across varying durations and intensities of VR-guided meditation and levitation, allowing us

Fig. 2 The VR environment for the guided meditation session. One of the co-authors demonstrating the session: **a** in a cross-legged position, **b** his virtual body levitating

to comprehensively assess a range of potential outcomes and interactions between different durations. The results of this broad exploration will serve as a foundation for more focused future studies. The TMS was used to assess the VR-guided meditation, while the FFMQ was used to provide additional information about participants' predisposition to meditate.

Given the novelty of VR-induced levitation, this research is exploratory in nature, serving as a foundational study to investigate potential interactions between meditation duration, levitation duration, and mindfulness-related experiences. With these premises, this study aimed at: (1) determining the skin conductance levels throughout meditation sessions and how these levels change during the levitation phase. We expect a decrease in skin conductance levels as the meditation practice evolves over time and a sudden change in these levels at the time of levitation, with longer meditation durations leading to a higher likelihood of experiencing levitation. We also expect, as the duration of the levitation increases, the novelty and intensity of the experience are likely to sustain or elevate arousal levels, which are reflected in higher SCLs. The prolonged engagement in a novel and immersive VR experience, such as levitation, is anticipated to enhance sympathetic nervous system activity, thereby increasing SCLs (Balderston et al. 2011; Kim et al. 2014). Thus, the 30-second levitation condition is predicted to show the highest SCLs, followed by the 20-second condition, with the 10-second condition showing the least increase in SCLs; (2) identifying the key factors within state-like meditation, trait-like meditation, and OBE responses that relate to VR-induced levitation experiences. Identifying these factors allows us to understand which specific elements of mindfulness and OBEs are most relevant to VR-induced levitation; (3) exploring the interplay between trait mindfulness, state mindfulness, and the subjective experience of VR-induced levitation. We hypothesize that higher levels of trait mindfulness and higher levels of state mindfulness are associated with a different subjective experience of VR-induced levitation. Mindfulness, both as a trait and as a state, involves heightened awareness and a non-judgmental approach to experiences, which may affect how individuals perceive and process VR-induced levitation.

3 Results

3.1 Statistical analyses

As a preliminary step, a test of sphericity was performed on EDA data. The Greenhouse-Geisser correction was applied to adjust for lack of sphericity in the ANOVA results. In line with the first aim, we performed a mixed analysis of variance to explore the impact of the time interval, as a within-subject factor, and the meditation and levitation duration, as between-subject factors, on the dependent variable, that is, the mean scores of skin conductance levels. A second two-factor ANOVA was performed to assess the effects of meditation and levitation factors on the variation of the SCLs during the levitation phase. Lastly, in line with the second and third aims, we performed a principal component analysis to understand which key aspects contribute most to the variance and a correlation analysis to examine the relationships between the different facets of the questionnaires.

3.2 Overall EDA results

The EDA data were collected using the Neulog software at a sampling frequency of 5 Hz per second. One participant's EDA measurement had to be discarded due to poor electrode contact, resulting in an empty recording. To ensure consistency and comparability across participant data, we normalized the EDA measurements. Normalization is crucial for eliminating individual baseline variations and providing a unified scale for analysis. The normalization was carried out using the formula described by Mandry & Atkins (Mandryk and Atkins 2007):

$$Normalized\ EDA_(i) = \left(\frac{EDA_(i) - EDA_{min}}{EDA_{max} - EDA_{min}}\right) \times 100 \quad (1)$$

Second, the normalized EDA responses per participant were averaged within a time window of 1 min, resulting in 5, 10, and 15 timestamps for the three meditation sessions (M5, M10, and M15), respectively. The EDA values for the levitation durations (L10, L20, and L30) were averaged from the start of the event at time=5, 10, or 15 min until its end after 10, 20, or 30 s. To facilitate comparison between conditions,

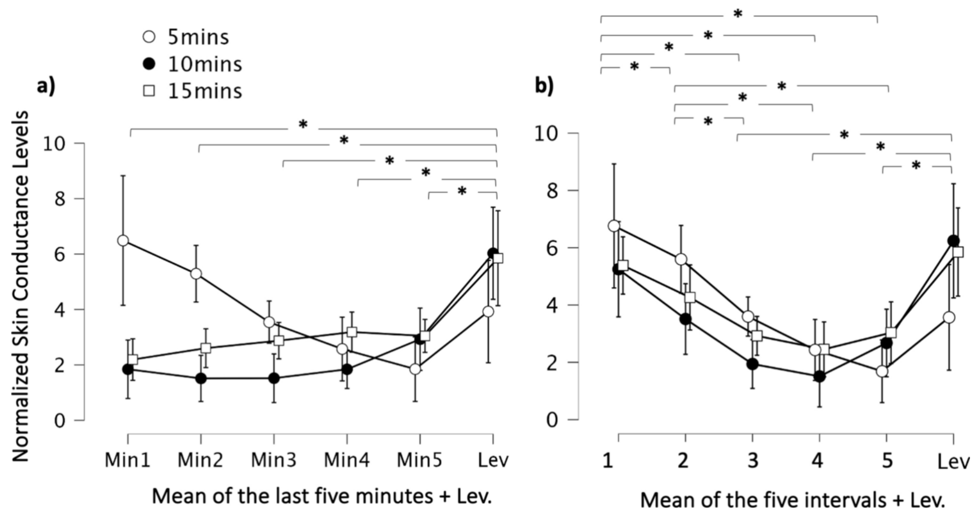

Fig. 3 Descriptive plots with 95% CIs for the three meditation groups (M5, M10, M15) for **a** the last 5 min + Levitation, **b** five-time intervals + Levitation

Table 1 Time intervals for EDA data for the three meditation conditions: M5, M10, and M15

Interval	1	Min2	3	4	5
M5 (5 mins)	Min 1	Min 2	Min 3	Min 4	Min 5
M10 (10 mins)	Mins 1–2	Mins 3–4	Mins 5–6	Mins 7–8	Mins 9–10
M15 (15 mins)	Mins 1–3	Mins 4–6	Mins 7–9	Mins 10–12	Mins 13–15

Table 2 Bootstrapped marginal means for different meditation duration

			95% BCA CI		
Group	Marginal mean	Bias	Lower	Upper	SE
5 mins	3.380	−0.047	1.885	4.946	0.768
10 mins	6.312	−0.002	3.395	7.888	1.056
15 mins	5.915	0.033	4.344	6.834	0.611

BCA: bias corrected accelerated

M10 and M15 were additionally averaged over time intervals of 2 and 3 min, respectively. The decision to analyze EDA responses in 5-minute increments was exploratory in nature and not tied to a specific hypothesis. This approach was taken to provide a more granular understanding of how physiological responses evolved over time, particularly during the meditation phase. While the primary focus was on the overall SCL trends during meditation and levitation, this time-interval analysis was included to generate additional insights into patterns that may emerge across different durations. Figure 3b illustrates the five intervals and the levitation phase, with Table 1 providing detailed information about the intervals. For comparison, Fig. 3a displays the EDA values for the last five minutes of each meditation duration, including the levitation phase.

After filtering and pre-processing the GSR data, the statistical analysis was conducted using JASP. To filter out unrelated noise from body movements or any additional artifacts, a threshold of 10 μS was set to exclude any SCLs above this value. A mixed ANOVA was performed on the mean EDA data, with Interval as a within-subjects factor and Meditation (5, 10, and 15 min) and Levitation (10, 20, and 30 s) as between-subjects factors. The ANOVA with repeated measures, incorporating Greenhouse-Geisser corrections, revealed a significant main effect of Meditation [F(2.58,62.98)=20.29, $p < .001$, $\eta_p^2 = 0.46$] and an interaction effect between Interval and Meditation [F(5.16,62.98)=2.96, $p < .05, \eta_p^2 = 0.2$].

Simple pairwise comparisons with Holm corrections revealed significant differences between Interval 1 and Intervals 2 to 5 ($p < .001$). Additionally, significant differences were found between Interval 2 and Intervals 3 to 5 ($p < .001$) and between the Levitation Interval and Intervals 3 to 5 ($p < .001$).

3.3 Levitation experience and EDA

One of the central aspects of our study was to understand participants' sensation of levitation and its physiological correlations. To this end, we closely examined EDA levels during the levitation phase for the nine conditions. To assess significance, we tested the hypothesis that the three meditation groups were different from each other using a two-factor ANOVA; the meditation factor with three levels (M5, M10, and M15) and the levitation factor with three levels (Lev10, Lev20, and Lev30) as between-subject factors. The meditation groups were significantly different from each other [F(2, 24) = 2.91, $p < 0.05$, $\eta^2 = 0.17$]. No additional effect was found. The ANOVA was followed by a post-hoc analysis and a bootstrapped marginal mean analysis to evaluate the response for the three meditation groups. The results are summarized in Table 2.

The post-hoc comparisons showed a significant difference between M5 and M10 ($p < .05$). This was corroborated by the marginal mean SDL that was highest at M10 (M = 6.312, SE = 1.056). The 95% bias-corrected and accelerated (bca) confidence interval [3.395, 7.888] indicates that we are 95% confident that the true mean SDL at M10 falls within this range. The bias for this estimate was very small (−0.002), suggesting that the bootstrap estimate is reliable. At 5 min, the marginal mean SDL was 3.380 (SE = 0.768), with a 95% bca confidence interval of [1.885, 4.946] and a small bias of −0.047, indicating a slight underestimation. This suggests that the SDL at M5 is significantly lower compared to M10, as the confidence intervals do not overlap. For the 15-minute group, the marginal mean SDL was 5.915 (SE = 0.611), with a 95% bca confidence interval of [4.344, 6.834] and a bias of 0.033. Although the mean SDL at M15 is lower than at M10, the confidence intervals overlap, suggesting that the differences between these two durations may not be statistically significant (see Fig. 4). In summary, the bootstrapped marginal means analysis indicates that the SDL decreases for M5 and slightly decreases for M15, with the most significant response observed at 10 min. The small bias values across all groups indicate the reliability of these bootstrap estimates.

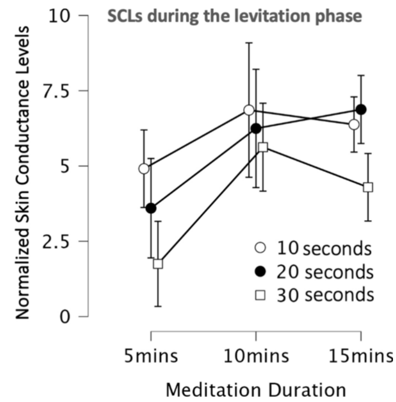

Fig. 4 Skin conductance levels for the Levitation phase for three meditation x three levitation duration. Error bars represent 95% CIs

3.4 Questionnaire results

As mentioned in the methods section, our study utilized various questionnaires, including the FFMQ, the TMS, and the OBLE, to gain insights into participants' experiences and perceptions. Here, we present the reliability and results of these assessments. Reliability was determined using Cronbach's α, which measures the internal consistency of items within a subscale. A principal component analysis (PCA) with a Promax rotation was used to determine which questionnaire items in the FFMQ, TMS, and OBLE form coherent subsets. Regarding the FFMQ, Cronbach's α of 0.60 indicated acceptable internal consistency. TMS and OBLE exhibited good internal consistency (Cronbach's α) of 0.74 and 0.70, respectively. The mean, standard deviations, and confidence intervals for each subscale are displayed in Table 3.

PCA using Kaiser's criterion to retain components with eigenvalues greater than 1 yielded three principal components (Table 4). Bartlett's test of sphericity ($\chi^2(36) = 111.93, p < .001$) indicated that the correlations between items were sufficient for PCA. The first component (PC1) accounted for 31.4% of the variance, while the second (PC2) and third (PC3) components explained 20.7% and 16.7% of the variance, respectively.

The first principal component is strongly correlated with three items. The first principal component increases with higher Physical Levitation, Curiosity, and Decentering scores. This analysis suggests that the Physical Levitation scores and the TMS items vary together. When one variable increases, the others tend to increase as well. This

Table 3 Mean, standard deviation (SD), and confidence intervals (CIs) for TMS, FFMQ, and OBLE subscales

Scale	Subscale	Mean	SD	CIs [lower–upper]
TMS	Curiosity	14.86	5.64	[13.02–16.70]
	Decentering	16.42	5.46	[14.63–18.20]
FFMQ	Observing	27.47	5.71	[25.61–29.33]
	Describing	26.56	6.54	[24.42–28.69]
	Mindful actions	25.53	7.83	[22.98–28.09]
	Non-judging	26.36	6.89	[24.11–28.61]
	Non-reactive	20.36	5.34	[18.62–22.10]
OBLE	Virtual (i.e., virtual body drifting upwards)	1.89	1.7	[1.33–2.45]
	Physical (i.e., real body drifting upwards)	1.19	1.90	[0.58–1.81]

Table 4 Principal component analysis component loadings

	PC1	PC2	PC3
Real body drifting upwards (Physical OBLE)	.861		
Curiosity (TMS)	.799		
Decentering (TMS)	.694		
Observing (FFMQ)		.858	
Non-reactive (FFMQ)		.820	
Virtual body drifting upwards (Virtual OBLE)		-.574	
Mindful actions (FFMQ)			.875
Non-judging (FFMQ)			.779
Describing (FFMQ)			.584

Values smaller than 0.5 are not shown

component can be considered a measure of Physical-Levitation Illusion and Mindfulness quality. Furthermore, the first principal component exhibits the strongest correlation with OBLE scores, with a correlation coefficient of 0.861. We could state that this principal component is primarily a measure of Physical OBLE. Therefore, participants with higher scores on the TMS tend to have higher Physical OBLE scores, while those with lower scores are less likely to experience a physical levitation illusion.

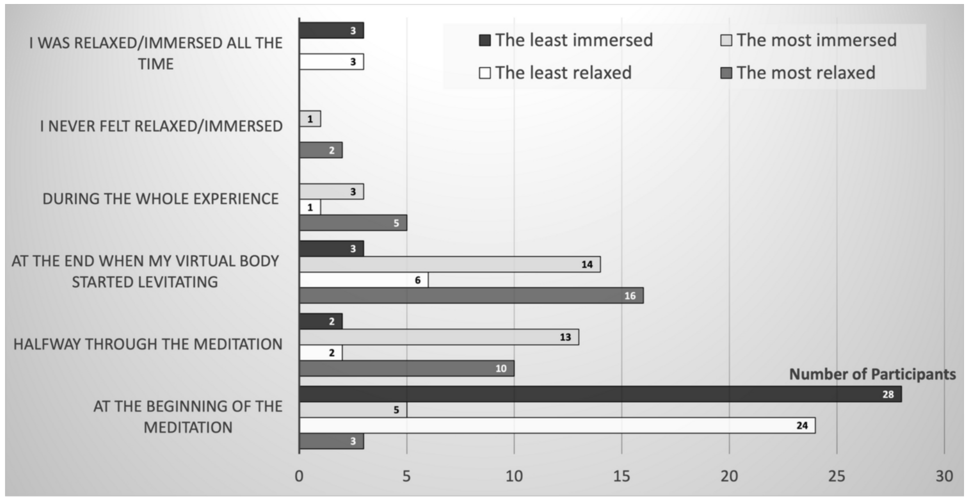

Fig. 5 Count of participants who reported when feeling the most and the least relaxed and immersed during the meditation session

The second component reflects the ability to observe without reacting. Interestingly, it correlates negatively with Virtual OBLE scores. Finally, the third component captures the ability to describe experiences and maintain awareness without being judgmental.

Bivariate correlations were conducted to examine the strength between the research variables and the direction of their relationships. Specifically, moderate positive correlations were observed between OBLE and Curiosity ($r = .42, p < .05$), OBLE and Decentering ($r = .51, p < .05$), and Decentering and Curiosity ($r = .59, p < .001$). A strong positive correlation was found between Observing and Non-Reactive ($r = .61, p < .001$). Both TMS items exhibited weak negative correlations with the Non-Judging item Decentering ($r = -.34, p < .05$)andCuriosity($r = -.36, p < .05$), while Describing ($r = -.44, p < .05$) and Mindful Actions ($r = -.54, p < .05$) showed a moderate positive correlation with Non-Judging.

3.5 Immersion and relaxation

In addition, participants were requested to indicate the moments during the meditation session when they experienced the highest and lowest levels of relaxation and immersion (see Fig. 5). Most participants reported feeling the least relaxed and immersed at the beginning of the meditation. Approximately one-third of the participants reported feeling the most relaxed and immersed when their virtual bodies began to levitate. Conversely, around one-third of the participants reported feeling relaxed halfway through the meditation.

4 Discussion

Our findings show a significant increase in EDA responses during the levitation phase compared to the preceding time interval. Regardless of the meditation duration, the overall EDA trend remained consistent across conditions, with high values in the early stages of meditation and gradually decreasing over time, suggesting that participants were actively following the voice instructions, which facilitated their focus on their breathing, relaxation, and mindfulness of their body and surroundings; patterns commonly observed in meditation practices. The decrease observed in SCLs over time is in line with previous findings where similar patterns of decreased physiological responses during immersive mindfulness experiences (Andersen et al. 2017; Huang et al. 2020).

The SCLs were higher during the levitation phase for the 10-minute meditation duration suggesting that this meditation duration maybe about right. The SCLs for 15-minute duration did not show substantial increase, while the skin conductance levels were significantly lower for the 5-minute duration. There is no real consensus on the duration of a VR-guided meditation or traditional meditation practice, but most studies had explore durations 5 to 30 min (Bieling 2012; Waller et al. 2021; Cinalioglu 2023; Riordan 2024). Besides, each person has different needs and responses to stressful situations and the way they meditate. Some would need a session as short as 5 min, while some will need 30 min. One relevant alternative is to use biofeedback to 1) determine the best time to trigger the levitatio, 2) modulate the timing of the levitation, and 3) control the height of the levitation from the ground. This last aspect was maintain fixed in our study, hence affecting the speed of the OBLE. EEG-based biofeedback has been successfully used in mindfulness studies by Arpaia et al. in enhancing emotional self-regulation, with both cognitive reappraisal and emotional acceptance effectively reducing high-beta band power in EEG measurements (Arpaia et al. 2022, 2021, 2022).

The SCLs were higher during the levitation phase for the 10-minute meditation duration, suggesting that this duration may be optimal. The SCLs for the 15-minute duration did not show a substantial increase, while the SCLs were significantly lower for the 5-minute duration. There is no consensus on the ideal duration for VR-guided meditation or traditional meditation practices, but most studies have explored durations ranging from 5 to 30 min (Bieling 2012; Waller et al. 2021; Cinalioglu 2023; Riordan 2024). Additionally, individual needs and responses to stress and meditation vary. Some individuals may benefit from sessions as short as 5 min, while others may require 30 min. A relevant alternative is to use biofeedback to 1) determine the best time to trigger levitation phase, 2) modulate the timing of the levitation, and 3) control the height of the levitation from the ground. This last aspect was kept constant in our study, affecting the speed of the OBLE across conditions. EEG-based biofeedback has been successfully used in mindfulness studies by Arpaia et al. to enhance emotional self-regulation, with both cognitive reappraisal and emotional acceptance effectively reducing high-beta band power in EEG measurements (Arpaia et al. 2022, 2021, 2022), making it a promising approach for OBLE in future studies.

Principal Component Analysis revealed that participants with a higher potential for observing experiences without reacting to them had lower scores for the virtual levitation experience. Conversely, participants who accepted the experience with curiosity (decentering) tended to have higher scores for physical levitation. This indicates that experiencing physical OBLE depends on multiple factors, including the ability to reflect on the immediate meditation session with acceptance, curiosity, and openness. Participants' comments about feeling warmth, the sun shining on their bodies, and the touch of the wind supported these findings. The ability of participants to non-react and simply observe significantly reduced the visual illusion of levitation, suggesting that the experience depends on meditative tendencies. The study by Airpaia et al. (2022) aligns with our findings, where the authors demonstrated that emotional acceptance combined with neurofeedback led to a decrease in high-beta power spectral density, suggesting an enhanced ability to regulate emotions. This is particularly relevant to our observation that participants who could accept their experiences with curiosity and non-judgment tended to have higher physical levitation scores. Emotional acceptance, described as paying attention in the present moment without judgment, parallels our findings where participants' openness and acceptance of the meditative experience influenced their perception of levitation. This non-judgmental awareness, akin to mindfulness, appears to play a crucial role in modulating physiological and subjective experiences during meditation and levitation.

Overall, our findings suggest that the combination of VR-guided meditation and levitation can significantly affect physiological responses and subjective experiences, with meditative tendencies playing a crucial role. Ladakis et al. discussed the potential of VR environments for stress reduction, emphasizing the importance of immersive experiences in promoting relaxation and mindfulness.

5 Limitations and conclusion

To the best of our knowledge, using self-views as stimuli in the context of vection research has yet to be explored. While most of the research on vection has primarily focused on stimulus-based approaches, such as using dots or lines (Howard and Howard 1994), only a few studies have addressed the impact of cognitive factors that are ecologically relevant to the participants (Riecke et al. 2006). Investigating self-motion or vection using this approach could offer valuable insights. Vection onset typically ranges from 2 to 30 s, with slightly over 10 s in VR settings, and can be accentuated by factors such as duration, perceived motion, and speed. In our future research, we intend to investigate these factors in depth by actively engaging participants through responses, such as pressing a button to indicate the perceived onset time and the direction of the self-motion in the context of OBLE.

Additionally, it is important to note that the OBLE in this study was purely visual. While VR OBE has been observed to occur in the absence of visuomotor or visuotactile synchrony, maintaining synchrony between motor actions and visual perception enhances the strength of OBE (Bourdin et al. 2017). Since participants were in a crossed-legged position, the absence of stimulus synchrony was minimized as participants' movement was limited. Given that VR multisensory meditation, using elements such as a fan, warm blanket, or scent helps alleviate anxiety and provide emotional relief (She et al. 2023), incorporating tactile feedback that mimics objects striking the virtual body could be beneficial in improving the current OBLE paradigm and enhancing the sense of embodiment in future studies. Overall, our study suggests that combining VR-guided meditation and out-of-body experiences has potential implications for embodiment and mindfulness practices. Further investigations into the levitation experience are necessary by exploring other durations and elevations from the ground and real-time video recordings.

Moreover, our findings must be considered in the context of the exploratory nature of this study and the sample size limitations, While this study provides valuable preliminary insights into VR-induced levitation, future research would greatly benefit from enrolling a larger sample size to ensure the robustness and generalizability of the observed effects. This initial exploration lays the groundwork for more focused studies with more robust sample sizes. Additionally, while this study provides valuable preliminary insights into the physiological and psychological effects of VR-mediated levitation, we acknowledge that the statistical power of the study was lower than ideal. Post-hoc analyses indicated that the power was approximately 0.41, suggesting that the study may be underpowered to detect smaller effects reliably. Given the sample size and the complexity of the design, we recommend interpreting the findings with caution. Future studies with larger samples will be necessary to confirm these trends and provide stronger statistical evidence for the effects observed in this study.

Finally, the unique and immersive nature of VR levitation presents challenges in establishing a traditional control group. The experience of VR levitation is distinct, and any alternative without VR would not provide a comparable sensory experience. While we considered potential control conditions, such as meditation without VR or VR without levitation, each has limitations in truly serving as a control for this novel paradigm. We emphasize the exploratory nature of this study, aiming to understand the potential of VR levitation. As our understanding of this intervention grows, future research may develop more appropriate control conditions.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10055-025-01138-9.

Author Contributions M.Z. designed the experiment, analyzed the data, and wrote the manuscript. R.J. programmed the experiment, contributed to its design, and ran the participants. A.G. cleaned and analyzed the EDA data and questionnaire scores. Y.D. planned and recorded the meditation sessions. He also helped with the questionnaire design. R.R. participated in the study design and provided the logistics for the study. All authors reviewed the manuscript before submission.

Funding Open access funding provided by Tampere University (including Tampere University Hospital).
This research was supported by Bentley University's Health Health Thought Leadership Network Seed Funds.

Availability of data and materials The datasets generated during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declared no Conflict of interest.

Ethics approval This study was approved by Bentley University's Institutional Research Board (IRB# 10042114)

Consent to participate All participants provided written consent for their involvement in the study.

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