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ORIGINAL PAPER

The Effects of Virtual Reality-Based Mindfulness Exercises on the Perception of Time, Psychological and Physiological States of Young People: A Randomized Crossover Trial

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Abstract

Objectives The purpose of this study was to assess and compare the efficacy of different electronic devices (VR headsets and tablet devices) supported mindfulness exercises. Contrary to previous studies, we compared the technologies not only regarding psychological but also physiological parameters. Additionally, we assessed time perception as an indicator of flow state, which can increase therapeutic adherence.

Method Fifty volunteers (26 females and 24 males) aged 19–28 years ($M=23$, $SD=1.93$ years) participated in our crossover trial. A 20-min mindfulness program (Guided Meditation VR™) was shown on both a VR headset and a tablet device, with a 1-week interval in randomized order. Psychological parameters and time perception were assessed through surveys, and an Empatica E4 wristband collected physiological data (heart rate, body temperature, electrodermal activity).

Results Both VR- and tablet-based mindfulness programs reduced stress, as reflected by improvements in both anxiety (a 7.06-point reduction in STAI-Y score, $p<0.001$) and in-session physiological parameters (a 4.82 bpm reduction in HR, $p<0.001$; 1.11 °C increase in body temperature, $p<0.001$), without significant differences between the two devices. However, participants perceived the intervention as shorter than its actual time only in the VR condition (VR: 26 shorter, 9 longer out of 47, $p=0.006$; tablet: 20 shorter, 14 longer out of 47, $p=0.39$).

Conclusions While affirming the efficacy of electronic device-supported mindfulness in stress reduction, our study suggests no significant disparity between VR and tablet-supported exercises. Our findings also suggest that participants in the VR session perceived the intervention as shorter than its actual duration.

Preregistration This study is not preregistered.

Keywords Anxiety · Mindfulness · Psychological well-being · Virtual Reality

Recent findings from the World Health Organization's World Mental Health Surveys initiative (Auerbach et al., 2016) highlighted that one in five college students grapples with mental health issues, primarily linked to stress or anxiety. Stress, as defined by Selye (1936), manifests as a non-specific bodily response to stimuli requiring attention or action. The American Psychological Association identifies stress and anxiety as two fundamentally akin emotional and physiological responses induced by stressors (American Psychological Association, 2022). Stress typically results from external triggers, whether short- or long-term, whereas anxiety usually derives from continuous, inner worries, which stay persistent even in the absence of specific stressors.

Although various methods exist, accurately estimating their intensity is challenging for professionals. Some focus on the subjective experience through self-administered surveys like the Stress and Adversity Inventory (Slavich & Shields, 2018) or the State-Trait Anxiety Inventory (STAI; Spielberger, 1983). By contrast, sympathetic responses elicited by stress are measurable through physiological parameters such as heart rate (HR), body temperature and electrodermal activity (EDA) (Siirtola & Röning, 2020). Physiological responses during stressful events in the human body are mostly attributed to the direct involvement of the hippocampus, amygdala, prefrontal cortex, autonomic nervous system (sympathetic and parasympathetic divisions),

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the hypothalamus–pituitary–adrenal (HPA) axis, and the sympathetic-adrenal-medullary (SAM) axis. Activation of these systems most importantly leads to increased adrenaline production, resulting in sympathetic predominance. This is evidenced by an elevated HR, decreased body temperature, reduced skin impedance and increased blood pressure, which are readily quantifiable (Ziegler, 2012).

While stress can be advantageous in evading dangerous situations, its chronic form poses substantial health and daily life challenges. Chronic distress is acknowledged as a significant causal factor contributing to a plethora of organic (e.g. functional gastrointestinal diseases, asthma, eczema) and psychiatric (e.g. panic disorder, depression, or chronic active alcoholism) illnesses (Agorastos & Chrousos, 2022). Regarding psychological problems, the impact of mental health issues during adolescence extends into adulthood, potentially leading to lower income or living standards (Gibb et al., 2010). Given the importance of these stress-related issues and acknowledging prevention as the most effective strategy against long-term negative outcomes, there is a necessity to investigate stress-reducing preventive measures.

Various forms of meditation are advocated for stress reduction, therefore, they may be effective in mental health prevention (Goyal et al., 2014; Lemay et al., 2019). Mindfulness—rooted in Buddhist traditions—is the practice of observing thoughts, emotions, and sensations in a non-judgemental manner. This type of meditation stands out as a particularly effective stress-relief technique (Sharma & Rush, 2014) and is mainly based on enhanced self-awareness (Creswell & Lindsay, 2014), inducing both psychological and physiological changes. Its efficacy extends to treating psychiatric disorders such as addictions (Bowen et al., 2014) and post-traumatic stress disorder (PTSD) (Polusny et al., 2015). Despite its numerous benefits, meditation remains relatively unpopular among the younger demographic, prompting the need for further exploration (Clarke et al., 2018).

In contemporary era dominated by technology, electronic device-supported therapies are gaining popularity, especially among young individuals. Virtual reality (VR), encompassing all kinds of artificial environments, is mostly well-known for the VR headset, creating a 3D simulated environment. There is a growing number of studies on the use of VR in psychological settings. For example, it has a positive effect on the mood of children (Erdős & Horváth, 2023) and adults undergoing chemotherapy (Gautama et al., 2023). Its distractive nature has also been used during venous phlebotomy (Gerçeker et al., 2018). In the realm of psychiatric application, an extensive array of studies has been conducted (Wiebe et al., 2022). Virtual environments may be beneficial treatment additions to psychological or psychiatric problems, including specific phobias, panic disorder and agoraphobia, social anxiety disorder, generalized anxiety disorder, PTSD, obsessive–compulsive disorder, eating disorders, dementia disorders, attention-deficit/hyperactivity disorder, depression, autism spectrum disorder, schizophrenia spectrum disorders, and addiction disorders. Moreover, studies suggest that VR can positively influence time perception (Schneider et al., 2011), attributed to its immersive quality facilitating the attainment of the *flow state*—an altered state of mind first described by Csikszentmihalyi (1990). During the flow state, a decreased prefrontal cortex and amygdala activity was observed (Dietrich, 2003), which can help in decreasing stress and anxiety. Regarding psychological health, studies suggest that this heightened state can support mental well-being (Bassi et al., 2022). On the other hand, flow state can lead to altered time perception, thereby promoting sustained adherence to mindfulness practices (Morin & Grondin, 2024; Rutrecht et al., 2021). Despite the potential benefits, immersive technologies may induce "cybersickness", a form of motion sickness characterized by symptoms like nausea, headache, dizziness, and eye strain. Nevertheless, no serious adverse effects have been reported.

Although an increasing number of articles investigate the efficacy of VR-based mindfulness exercises (Arpaia et al., 2022; Ma et al., 2023; Modrego-Alarcón et al., 2021), the literature concerning the comparative analysis of this technology with other electronic devices is still limited. In a study by Kaplan-Rakowski et al. (2021), the effects of mindfulness meditations presented via VR or a computer were compared using a between-subject design. The primary focus was on enhancing exam performance, possibly through reducing pre-exam anxiety levels. A significant difference was found in the change in test performance between the two groups. However, this difference was primarily driven by a decrease in performance observed in the computer group. In a pilot randomized trial conducted by Poetar et al. (2023), VR and desktop-based mindfulness meditations were compared. The study aimed to assess the impact on negative and positive emotions using the Positive and Negative Affect Schedule questionnaire. Both VR and computer-based mindfulness practices were found to effectively decrease negative emotions. Notably, positive emotions exhibited a significant increase exclusively in the VR condition. Importantly, there were no reported instances of significant cybersickness syndrome. These findings suggest potential advantages of VR-based mindfulness meditation over computer-based methods, particularly in enhancing positive emotions. However, to establish the superiority of VR-based mindfulness meditation in enhancing positive and alleviating negative emotions, further studies are needed.

Our study aimed to assess and compare the efficacy of VR headset- and tablet-supported mindfulness exercises. In contrast to previous studies, we aimed to measure not only psychological parameters but also physiological variables and time perception. Incorporating physiological parameters—such as sympathetic responses elicited by stress, including HR, body temperature, and EDA (Siirtola & Röning, 2020)—and considering time perception in such studies may provide valuable insights and help clarify the underlying mechanisms of these observed effects. The hypotheses in this research were the following: (1) In the VR condition, there is a larger reduction in anxiety reflected by the STAI-Y score compared to the tablet condition. (2) In the case of the VR condition, there is an increased parasympathetic dominance reflected by HR, body temperature and EDA when compared to the tablet condition during and after the intervention. (3) Individuals immersed in the VR experience perceive the duration of the exercise as shorter than its actual length, differing from the tablet condition.

Method

Participants

Participants were recruited via social media (through Facebook groups), targeting young volunteers meeting specific eligibility criteria. Inclusion criteria were age between 18 and 30 years, possessing self-reported basic proficiency in English, and currently enrolled or having completed university studies. A total of 50 volunteers (26 females and 24 males, 47 university students) were selected, with ages ranging from 19 to 28 years ($M=23$, $SD=1.93$ years). All 50 volunteers were available to attend both scheduled mindfulness sessions.

Procedure

The research adhered to the principles outlined in the Declaration of Helsinki, and ethical approval was granted by Semmelweis University Regional and Institutional Committee of Science and Research Ethics. Data collection took place between October 2020 and June 2021. The methods and outcomes of this study were reported in accordance with the extension of the CONSORT 2010 checklist for crossover trials (Dwan et al., 2019; Supplementary Information).

The study employed a randomized cross-over trial design to investigate and compare the impact of two different device-supported mindfulness interventions on time perception, physiological responses, and psychological changes in young adults. Participants engaged in two mindfulness sessions, one delivered through a VR headset (experimental condition) and the other through a tablet device (control condition). The order of the conditions was randomized according to a random sequence generated before the start of the study, resulting in 25 participants commencing their first session with VR and 25 with the tablet. Due to the nature of the intervention, neither the participants nor the experimenter was blind to the condition. Prior to the initial mindfulness session, participants received a briefing detailing the research and provided written consent.

The meditation practices were administered using an Oculus Go VR headset (Oculus VR LLC, California, USA, 2018), and a Samsung Galaxy Tab A tablet device (Samsung Electronics, Suwon, South Korea, 2019) equipped with an Acer Predator Galea 311 (Acer Inc., New Taipei City, China, 2020) headset. The mindfulness exercise for the study was delivered by the Guided Meditation VR™ application (Cubicle Ninjas, Chicago, USA, 2018). A 20-min relaxation program in English, without background music, and set in a virtual beach environment (Costa del Sol) was selected. A female voice guided the participants through the exercises, which contained breathing exercises, body scanning, and visualization (the participants had to imagine birds flying in the virtual surroundings). The exercise was recorded using the internal recording system of the VR device and subsequently downloaded as a 20-min, 2D video with identical sound and visual effects for application on the tablet device.

The data collection occurred in a quiet room within an office environment to ensure a peaceful atmosphere. Upon arrival, participants had the Empatica E4 device attached to their left wrist. Subsequently, each participant was directed to complete the initial 20 questions related to state anxiety on the STAI-Y. Following the completion of the survey, participants engaged in the mindfulness video session presented on the assigned device. At the end of the exercise, participants were prompted to revisit the STAI-Y, responding to the same initial 20 questions, and were also asked a short question regarding time perception. After the start of the trial, there were no changes in the methodology and outcomes. The experiment was conducted until 50 participants were included as per our intended sample size.

Measures

To measure state anxiety, the State-Trait Anxiety Inventory for Youth (STAI-Y) was used. The STAI-Y is a validated (Thomas & Cassady, 2021) psychological assessment tool designed to measure anxiety levels in children and adolescents; we used the validated Hungarian form of the scale (Sipos & Sipos, 1983). The inventory uses self-report scales, allowing young respondents to rate their feelings of anxiety at the moment (state) and in general (trait). Internal consistencies for this sample were $\alpha=0.91$ and $\omega=0.91$. Physiological data were recorded using an Empatica E4 wristband (Empatica Inc., Cambridge, USA). The parameters measured were: HR (average heart rate values, computed in spans of 10 s), body temperature (from the temperature sensor expressed in degrees on the Celsius (°C) scale sampled at 4 Hz), and EDA (through the electrodermal activity sensor in μS sampled at 4 Hz). The Empatica device uploaded the collected data to the Empatica's

Web Portal, E4 connect. The interface allowed us to visualize E4 session data and download sessions in csv format. Time perception was assessed with the question: "How long do you think the exercise lasted?".

Data Analyses

Metrics related to pre- and post-exercise states were computed by averaging data over a two-minute period before and after the mindfulness session, respectively. Data during the session were also averaged. State anxiety scores were calculated in accordance with the STAI-Y Manual (Spielberger, 1983) and raw scores were used for analysis.

The raw HR, body temperature, and EDA data were processed using R Statistical Software (v4.3.2, R Core Team, 2021). The choice of these parameters aligns with findings from a prior study (Siirtola & Röning, 2020), demonstrating notable sensitivity and specificity in the context of personal stress detection. These measures indicate parasympathetic changes in the participant's body, as an indicator of relaxation.

HR was averaged in 10 s epochs, while body temperature and EDA measurements were sampled at a rate of four times per second. For EDA, considering substantial individual variability, we applied a bandpass filter with a minimum of 0.01 µs and a maximum of 100 µs. In the case of the other two variables (HR and body temperature), no filter was used as values were within the physiological limits. Subsequently, all HR, body temperature and EDA signals underwent visual inspection to identify any abnormal signals or periods of unstable recording during the interval of the data capture. No data were removed due to bad signal quality. We averaged data over a 2-min period before the start and after the end of the mindfulness session for statistical analyses.

For statistical analysis, a repeated-measures analysis of variance (ANOVA) with paired *t*-tests for post-hoc analysis was employed. Physiological parameters and STAI-Y served as dependent variables, with time and condition acting as within-subject factors.

Additionally, sign tests were performed separately for the VR and tablet conditions to test if underestimation and overestimation of the actual intervention time differed from zero. To address the issue of multiple comparisons, a Bonferroni correction was applied, with a significance threshold set at $p = 0.025$ for rejecting the null hypothesis. Statistical analysis was performed by R (v4.3.2, R Core Team, 2021).

Results

The two mindfulness sessions were separated approximately 1 week apart ($M = 7.04$ days, $SD = 0.35$ days), with each session lasting between 23 and 32 min (20 min of mindfulness exercise, while the remaining time was spent with the STAI-Y questionnaire and the question regarding time perception) ($M = 27.80$ min, $SD = 1.77$ min). Throughout the sessions, only one participant reported experiencing mild dizziness and headache after engaging in the VR-based mindfulness session. Importantly, the participant demonstrated both the willingness and ability to complete the mindfulness exercise entirely despite these reported sensations. The participant flowchart can be seen in Fig. 1.

Psychological Parameters

State Anxiety

One participant was excluded from analysis due to misunderstanding the STAI questionnaire and reporting the problem only after the mindfulness session. The analysis revealed no significant main effect of condition ($F(1, 48) = 0.76$, $p = 0.39$) or interaction effect ($F(1, 48) = 0.06$, $p = 0.81$) between session and VR ($M_{before} = 37.10$, $SD_{before} = 8.13$, $M_{after} = 29.41$, $SD_{after} = 5.78$) and tablet ($M_{before} = 36.66$, $SD_{before} = 8.52$, $M_{after} = 28.30$, $SD_{after} = 6.20$) conditions concerning the state anxiety score. However, a significant reduction ($F(1, 48) = 164.47$, $p < 0.001$, *Generalized Eta Squared* = 0.23) was observed between the before-exercise ($M = 47.46$, $SD = 7.35$) and after-exercise ($M = 40.40$, $SD = 5.35$) measures. These findings suggest that both mindfulness sessions were equally effective in reducing anxiety.

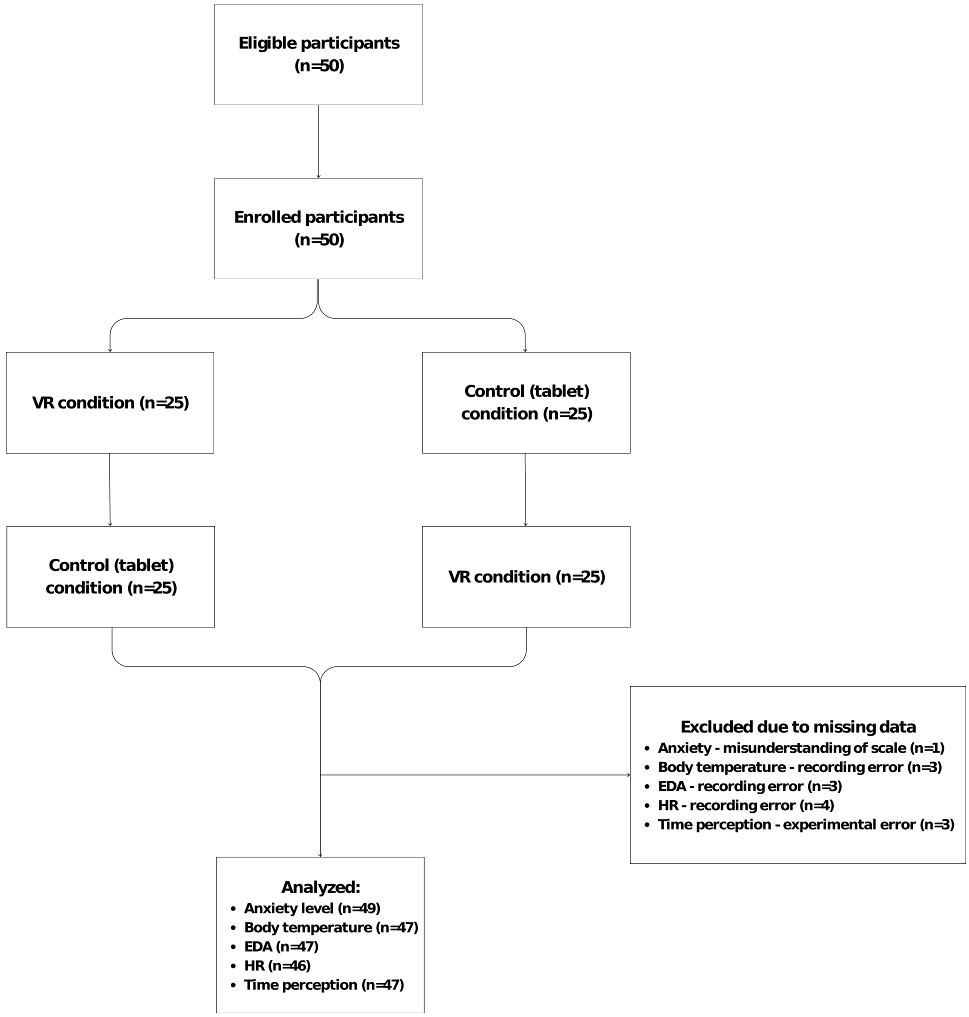
Physiological Parameters

Using repeated-measures ANOVA, no significant main effect of condition was found for HR ($F(1, 45) = 1.31$, $p = 0.26$), body temperature ($F(1, 46) = 3.33$, $p = 0.07$), and EDA ($F(1, 46) = 0.007$, $p = 0.93$). Likewise, the interaction effect was not significant for HR ($F(2, 90) = 0.31$, $p = 0.73$), body temperature ($F(1.21, 55.57) = 2.18$, $p = 0.14$), and EDA ($F(1.32, 60.84) = 0.59$, $p = 0.49$).

A significant main effect of the session was discovered regarding HR ($F(2, 90) = 10.58$, $p < 0.001$, *Generalized Eta Squared* = 0.03). Post-hoc *t*-tests revealed a significantly lower HR during the mindfulness session compared to before ($t(91) = 4.14$, $p < 0.001$, $d = 0.17$) and after session HR ($t(91) = 3.37$, $p = 0.001$, $d = 0.25$), but there was no significant difference between the pre-and post-session measures ($t(91) = 1.70$, $p = 0.09$).

Similarly, a significant main effect of the session was observed for body temperature ($F(1.09, 50.36) = 60.93$, $p < 0.001$, *Generalized Eta Squared* = 0.09). Post-hoc tests showed a significant increase in body temperature between

Fig. 1 Participant flow chart



pre- and intersession ($t(93) = 9.05$, $p < 0.001$, $d = 0.46$), intersession and post-session ($t(93) = 6.74$, $p < 0.001$, $d = 0.36$), and pre- and post-session ($t(93) = 8.87$, $p < 0.001$, $d = 0.75$).

No significant main effect of the session was observed in EDA ($F(1.33, 61.21) = 2.32$, $p = 0.13$). The means and standard deviations of the physiological parameters are summarized in Table 1.

Time Perception

Due to missing data, 47 participants were analyzed. The sign test revealed a significant difference in the number of positive and negative signs from zero in the VR condition ($p = 0.006$). In contrast, there was no significant difference in the tablet condition ($p = 0.39$). Specifically, there were 9 instances of positive differences and 26 instances of negative differences in the VR condition, indicating a consistent tendency for participants to underestimate the actual intervention time. In the tablet condition, there were 14 instances of positive differences and 20 instances of negative differences.

Discussion

The escalating prevalence of mental health issues among young individuals in modern society (Auerbach et al., 2016) accentuates the need for effective psychological prevention techniques, with mindfulness exercises being a prominent consideration (Sharma & Rush, 2014). Young individuals, in particular, tend to favor contemporary technological solutions for health-related purposes. In this study, we aimed to assess and compare the efficacy of VR and tablet-supported mindfulness exercises in terms of time perception, psychological, and physiological changes in young adults. The cross-over trial design required each participant to undergo the same mindfulness program on both a VR headset (experimental condition) and a tablet (control condition). In summary, our results indicate that both conditions were equally effective in decreasing anxiety and inducing a parasympathetic response, despite individuals in the VR condition perceiving the intervention as shorter than its actual duration.

Table 1 Means and standard deviations by condition before, during and after the mindfulness practice

	VR *Means* (*SD*)			Tablet *Means* (*SD*)			Total *Means* (*SD*)		
	before	during	after	before	during	after	before	during	after
Anxiety (score)	37.10 (8.13)	-	29.41 (5.78)	36.66 (8.52)	-	28.30 (6.20)	47.46 (7.35)	-	40.40 (5.35)
HR (bpm)	83.06 (12.03)	77.63 (14.42)	80.55 (10.42)	79.88 (10.15)	75.68 (14.78)	78.91 (9.22)	81.47 (11.18)	76.65 (14.55)	79.73 (9.82)
Body temperature (°C)	32.25 (2.13)	33.27 (1.92)	33.75 (2.00)	31.33 (2.91)	32.54 (2.40)	33.34 (2.14)	31.79 (2.58)	32.90 (2.19)	33.55 (2.07)
EDA (μS)	2.23 (3.20)	1.60 (2.06)	1.92 (2.40)	2.03 (2.91)	1.83 (3.19)	1.99 (2.77)	2.13 (3.05)	1.71 (2.68)	1.95 (2.58)

Regarding time perception, our findings suggest that VR positively influences time perception in young healthy volunteers, building on the impact previously observed in chemotherapy patients (Schneider et al., 2011). The immersive virtual environment, fostering a "flow state", may contribute to this effect (Rutrecht et al., 2021), potentially enhancing the long-term adherence to the meditations and promoting a more intense state of meditation as previously observed (Kaplan-Rakowski et al., 2021). However, further research is needed to confirm this potential benefit of VR technology. Regarding additional variables, our results align with prior observations (Kaplan-Rakowski et al., 2021; Modrego-Alarcón et al., 2021) indicating that electronic device-supported mindfulness interventions effectively reduce stress. This reduction was evident not only in decreased anxiety levels but also in physiological parameters, with a decrease in HR and an increase in body temperature during the exercises. These changes align with a parasympathetic response observed in previous meditation studies (Jerath et al., 2014). Our outcomes indicate no significant difference between VR and tablet conditions concerning anxiety and physiological parameters (HR, body temperature, and EDA). Despite one self-reported case of cybersickness (dizziness and mild headache), all participants completed the meditations during the VR sessions without major challenges, affirming the safety of VR as a meditation tool.

Limitations and Future Research

One of the main limitations of this study was that most participants were unfamiliar with VR technology, potentially triggering a sympathetic response in their bodies which may have affected our findings. To evaluate the significance of this phenomenon and considering that most mindfulness-based stress reduction (MBSR) programs typically span 8 weeks with at least 1 hr per week (Ito et al., 2022), we aim to extend our research with additional sessions and prolonged mindfulness practices to obtain more substantial results regarding mental health impact and overall well-being. Also, due to the pilot nature of our study and the constraints on personal interactions imposed by the COVID-19 pandemic, we did not conduct follow-up assessments with home practice to determine the long-term sustainability of these effects. We plan to address this aspect in future studies too.

Additionally, the mild immersion effect of the meditation program (Best et al., 2022) used in our experiment could have influenced our measures. Using a more immersive meditation program could have caused a significant difference between the VR and tablet devices regarding psychological and physiological measures, and it could have caused a larger difference regarding time perception. Future studies could benefit from regular mindfulness sessions to assess the long-term impact of time perception on therapeutic adherence. Moreover, it would be advantageous to investigate the efficacy of electronic device-supported mindfulness in children, who may be even more receptive to technology, and within clinical environments in which the distractive effects of electronic devices may help to focus.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12671-024-02438-y.

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Author Contributions Orsolya Olasz: Conceptualization, formal analysis, investigation, resources, data curation, writing original draft preparation, writing-review and editing, visualization. Sándor Erdős: Conceptualization, methodology, formal analysis, resources, writing original draft preparation. Klára Horváth: Conceptualization, methodology, formal analysis, resources, writing original draft preparation, writing-review and editing, visualization, supervision.

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Data Availability Data is available upon request from the corresponding author.

Declarations

Ethics Statement The study was conducted in accordance with the Declaration of Helsinki and approved by the Semmelweis University Regional and Institutional Committee of Science and Research Ethics (registration number: SE RKEB 183/2020, registration date: 08/01/2021).

Informed Consent All subjects gave their informed consent prior to study inclusion.

Conflict of Interest The authors declare no competing interests.

Use of Artificial Intelligence Statement Artificial Intelligence (ChatGPT and Grammarly) was used for editing the manuscript to improve English language.

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