VR-Hiking: Physical Exertion Benefits Mindfulness and Positive Emotions in Virtual Reality

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Fig. 1. In a lab study, we demonstrated that a physically demanding task, such as hiking up a mountain on a treadmill in a simulated environment in VR, has a positive effect on the user. Physical exertion changes the user experience, and physically walking positively impacts emotions, mindfulness, and wellbeing.

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Exploring the great outdoors offers physical and mental health benefits. Hiking is healthy, provides a sense of accomplishment, and offers an opportunity to relax. However, a nature trip is not always possible, and there is a lack of evidence showing how these beneficial experiences can be replicated in Virtual Reality (VR). In response, we recruited (N=24) participants to explore a virtual mountain landscape in a within-subjects study with different levels of exertion: walking, using a chairlift, and teleporting. We found that physical exertion when walking produced significantly more positive emotions and mindfulness than other conditions. Our research shows that physically demanding outdoor activities in VR can be beneficial for the user and that the achievement of hiking up a virtual mountain on a treadmill positively impacts wellbeing. We demonstrate how physical exertion can be used to add mindfulness and positive affect to VR experiences and discuss consequences for VR designers.

CCS Concepts: • **Human-centered computing** → *Haptic devices*; *Empirical studies in interaction design*; *Virtual reality*.

Additional Key Words and Phrases: virtual reality, haptics, accomplishment, presence, wellbeing

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1 INTRODUCTION

Click. You're standing on the top of a jagged, snow-capped mountain looking out over the surrounding peaks. ***Click***. You're drifting through space and look down at the surface of a beautiful planet below that you have never seen before. ***Click***. You look over a tranquil, idyllic beach as waves gently crash along the shore.

In Virtual Reality (VR), we have the power to teleport instantly to any location or scenario we can imagine. The opportunities for virtual exploration are immense, but how does instant transportation affect our experience? It is often said that the journey is as important as the destination, but with the power to teleport to any virtual location, VR experiences often remove the journey completely. Consequently, it remains a challenge for Human-Computer Interaction (HCI) to understand how users perceive traveling between locations in VR and how such journeys can be designed to produce a positive user experience. Further, as virtual environments become more realistic, exploring if and how some travel experiences can be substituted with VR counterparts may be useful.

Concurrently, the HCI field has recognized the need to more efficiently include walking as part of everyday interactions with technology [11, 17, 19]. There is a body of work [1–3] aimed at persuading users to walk more, motivated primarily by the physical and mental benefits of walking. In particular, research shows that walking can be a tool to foster mindfulness—a state of living in the moment [24]—which can, in turn, positively impact wellbeing. There is evidence that walking provides psychological [39] and physiopsychological [4] benefits through fostering mindfulness. Other studies found that modes of transportation, such as taking the bus, walking, or riding a bicycle, also offered stress reduction and fostered mindfulness [30]. Thus, given that real-life locomotion experiences can bring meaning and health benefits to our life, the following questions emerge:

RQ1: *Can physical exertion change the way users experience a virtual scene?*
RQ1a: *Can we replicate the wellbeing benefits of hiking in VR?*
RQ1b: *Can physical exertion in VR increase users' wellbeing?*

To investigate these research questions, we conducted a lab study exploring the effect of different modes of travel on the user's perception of a VR experience. We built a virtual environment where users explored a mountain landscape by using different modes of transportation to reach the top of

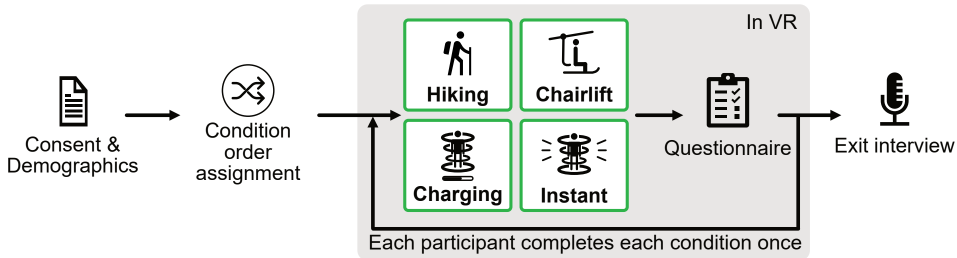

Fig. 2. Study Procedure: Participants complete a consent form and a demographics questionnaire. The participants are then assigned a counter-balanced condition order and complete all four conditions: Hiking, Chairlift, Charging, and Instant. Participants respond to an in-VR questionnaire after each condition and an exit interview after completing all conditions.

the mountain. In a within-subjects study with N=24 participants, we compared walking, using a chairlift, and two versions of a virtual teleporter. Users walked on a treadmill, sat on a chair, and entered virtual teleportation portals to explore the effects of physical exertion, visual movement, and time. We collected data on perceived exertion, experience, emotions, and mindfulness using in-VR questionnaires and exit interviews.

We found that walking produced significantly higher levels of positive emotions and mindfulness compared to the other conditions. Our results show that walking in VR can be used to build virtual experiences that foster mindfulness. We observe that using different modes of transportation in VR can be used to foster positive feelings in users, similar to real-life locomotion. This work contributes a study of the user experience and effects on the users' mental state of different modes of transportation in VR and discusses the consequences for designing VR experiences that benefit users' wellbeing.

2 RELATED WORK

In the following, we add context to our work by introducing the concept of presence in VR and then discussing the use of treadmills in virtual environments. We then review the effect of VR on reality and finally analyze past work on health and wellbeing in VR.

2.1 Being There: Presence in VR

The Technical side of the Mixed Reality continuum [36] is described by the immersion (i.e., the level of fidelity) the system can offer [50]. The strong side of Virtual Reality (VR) is to fully immerse somebody in a virtual environment. This is evaluated by the human response, in the form of presence, to such immersive virtual environments that create the sensation of "being there" [23, 50]. Past work has investigated the impact of perceived body consciousness on presence and found no significant link [32]. Similarly, prior research on exergaming [7] and gaming with omnidirectional treadmills [61] found no impact of exertion on presence. Conversely, past work has found that gait-synchronized stepping sounds increase presence and self-agency in virtual environments [21]. Incorporating social touch has been shown to not only increase co-presence but also impact the perceived agency of virtual characters [22].

2.2 Taking Steps: Treadmills and VR

Treadmills are associated with creating a realistic VR experience. Omni-directional treadmills are commonly found in arcades and famously appear in the movie Ready Player One. Using a treadmill in VR has obvious benefits; users can experience walking sensations without requiring a large tracked VR space. Using VR while on a treadmill actually improves treadmill gait patterns [53] and has no impact on walking pattern stability [16]. By adjusting optical flow patterns [9], users can experience a natural walking speed, which can also be adjusted to trick users into experiencing manipulated spatial distances [10]. In our work, the treadmill is a key tool to enable participants to experience physical exertion while moving through the virtual space. Contrary to the majority of past research, we do not use a treadmill to offer an as-realistic-as-possible way of traversing a VR environment. Instead, the treadmill allows our system to induce exertion where the act of walking on a treadmill in a virtual environment is at the core of the experience—the walking is the main activity.

2.3 Simulating the Real Thing: The effect of VR on Reality

Although VR is most commonly used to experience fictional scenes, such as in gaming, there are many applications where users experience a simulated version of a real place on earth, such as virtual museums [12] or virtual nature [29].

The effect of experiencing simulated scenarios on users is dependent on the type of experience. Researchers have found that users who undertake a 'cognitive experience', such as a museum, in VR no longer feel the need to go to the real museum, while users who experience virtual travel feel more inclined to visit the real location afterwards [12]. Virtual nature experiences motivate users to donate to and support national parks but do not motivate them to support local nature [31]. The effect of virtual nature, however, is dependent on the individual. People with a low requirement for emotional arousal are more likely to be satisfied by a virtual nature experience, while people who seek social interaction or physical exercise while traveling are more likely to be dissatisfied [41]. Reetz et al. [42] found no difference in stress levels between virtual nature and urban scenes, although prior work has shown that our affinity for nature, or biophilia [62], can have restorative effects in VR [58].

The most similar prior work to our approach was a VR rock climbing wall implemented on a climbing treadmill [28]. The climbing treadmill moved in the physical world, and users climbed while a virtual rock wall was displayed in their headset. They showed that the haptic feedback conveyed by using a realistic physical device was effective in creating an engaging experience. Our work differs from this approach by focusing on general locomotion, which is applicable to haptics, wellbeing, and video game design.

2.4 Virtual Sweat: Health and Wellbeing in VR

VR can be used to make exercise sessions more motivating and interesting by enabling users to work out in any virtual location. People exercise harder in VR and enjoy it more without perceiving the extra effort they are exerting [37]. Similarly, prior work has shown that participants exercising in VR experience lower pain and exhibit a longer time to exhaustion [32], and that perceived exertion can be altered by manipulating virtual representations [33]. This effect is further explained by the fact that VR has been shown to reduce responses to negative sensations [35]. Furthermore, VR can reduce stress — positive experiences when training in VR tends to lead to lower stress and workload when performing a live version of the same task [29].

Prior work has used VR as a tool to encourage exercise through the development of exergames. These exergames incorporate exercise into virtual sports such as cycling [5], skiing [27], and running [63]. Rather than using VR as a means to induce exercise, we use exercise and effort as a means to study mindfulness in VR. There is no consensus definition of mindfulness in HCI to date [56], so for the purpose of this study, we follow a definition similar to Kabat-Zinn [24]—having focused attention and awareness on the present moment. We observe that past research has not

Fig. 3. Participant-perspective views at the start of each condition at the foot of the hill: (a) Hiking (b) Chairlift (c) Charging (Teleport) (d) Instant (Teleport)

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explored how mindfulness experiences can be implemented in VR using locomotion. Thus, our work investigates if there are potential wellbeing benefits to mindful locomotion in VR.

3 METHOD

To study locomotion in VR and its impact on the users, we designed a within-subjects study where the participants were tasked with reaching the top of a virtual mountain in four conditions (see Figure 2 for an overview). The study took place in a virtual space filled with a picturesque mountainous area full of trees and grass. In each condition, the participant started at the foot of a mountain and followed a straight path toward the top of the mountain, either by hiking (walking), riding a chairlift, or using two forms of teleportation. At the end of the path, at the top of the mountain, the participants could find a viewing platform and enjoy the mountain view with a blue sky. The scene on top of the mountain featured a perfect sky, lakes in the distance, hills, and fog in the far distance to limit the rendered area. The study was conducted in a lab setting and followed local safety regulations.

3.1 Participants

We recruited N=24 participants aged 22-58 (M=25, SD=7.18), 12 participants identified as male and 12 as female. All participants reported having normal or corrected to normal vision. The study was approved by the local ethics committee (<details removed for review>). The participants had a self-reported estimate of their VR experience between 1 (never used) and 5 (used regularly/for many hours) (M=3.5, SD=1.24). None of the participants reported increased levels of motion sickness (all ratings < 10). This rating was used to ensure the wellbeing of the participants, and while higher ratings would have resulted in aborting the trial, it did not serve as an additional dependent variable.

3.2 Conditions

We designed four conditions for the study, as shown in Figure 3. The conditions represent alternative methods of reaching the top of the mountain (shown in Figure 4). We created the hiking condition

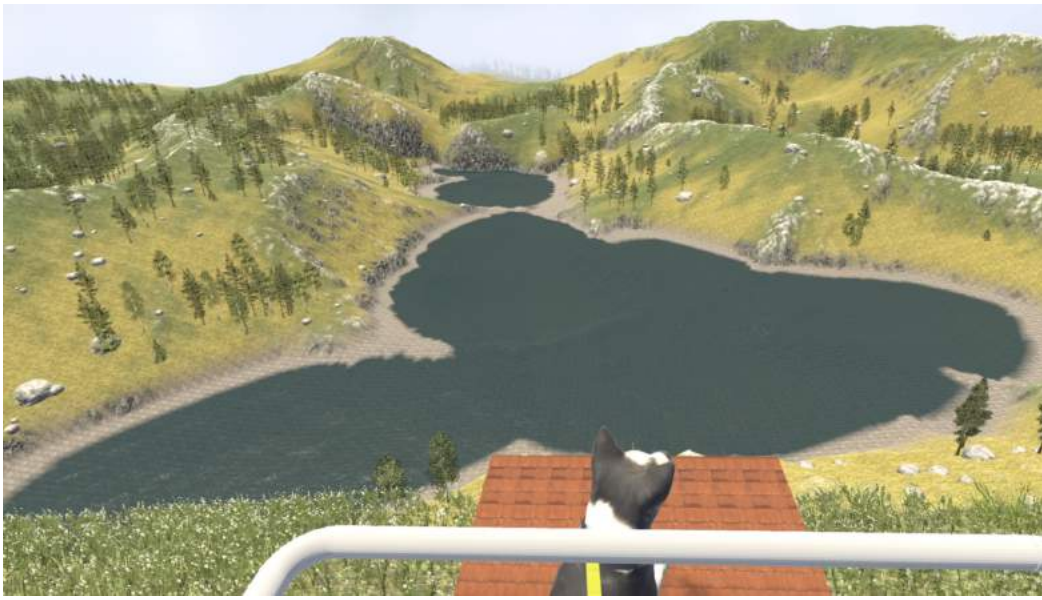


Fig. 4. Upon reaching the top of the mountain, the participant is greeted by a view over a beautiful valley, while being able to relax on a wooden platform.

to replicate the experience of hiking up a mountain and enjoying the view from the peak. We use a treadmill to recreate the physical exertion of real-world hiking while wearing an HMD. To mirror the ability of VR to instantly transport a user into any situation or place, and therefore removing the physical exertion required to reach that place, we created the INSTANT teleport condition. These two conditions, hiking and instantly teleporting, include three design elements (see Table 1) that contribute to the VR experience: physical exertion, visual movement, and time. We, therefore, designed the CHAIRLIFT condition to control for the effects of visual movement and time without physical exertion. We further developed the teleport CHARGING condition, which takes the same amount of time as the HIKING and CHAIRLIFT conditions, without any visual movement.

The HIKING, CHAIRLIFT, and CHARGING conditions all required traveling for 4.5 *min* to reach the top of the mountain. In the INSTANT condition, the participant was immediately moved to the top of the mountain. The order of conditions was counterbalanced using a Latin Square [8].

3.2.1 Hiking. In the HIKING condition, the users walked up the mountain. We implemented this mode of transportation with a treadmill that adjusted its incline according to the changes in a 3D scene. As the participants were not able to see their position in relation to the treadmill, we introduced a dog leash to be held in hand as a guidance tool. In the VR scene, a dog was leashed and guided the participant up the mountain. This ensured that the participant kept the right speed and position on the treadmill while also creating the feeling of being pulled by the virtual dog. This, in turn, prevented the participant from stepping outside of the treadmill. When the participant signaled that they were ready, the treadmill, dog, and VR path slowly started moving. The treadmill then gradually increased its speed and angle. If desired, the participants could signal to slow down the treadmill. The walking route was a straight path up the hill with a flat stone texture. When reaching the top, the treadmill slowed down, and the incline was gradually reduced. Once the

Conditions \ Design elements	Physical Exertion	Visual Movement	Time
Hiking	✓	✓	✓
Chairlift		✓	✓
Teleport Charging			✓
Teleport Instant			

Table 1. The Factors (Physical Exertion, Visual Movement, and Time) involved in each of the four experimental conditions.

participant reached the viewing platform, the dog and treadmill stopped, and the participants could explore the view.

3.2.2 Chairlift. The chairlift represents a travel modality that requires the same time and featured the same amount of visual movement as hiking but without physical exertion. We placed the participants in a chairlift that traveled to the top of the mountain. The participants sat on a physical chair. When they signaled that they were ready, the chairlift started moving. When reaching the top of the mountain, the HMD shortly faded to black and then placed the participant on the platform next to the chairlift.

3.2.3 Charging (Teleport). In the charging condition, the participants completed travel which required the same amount of time as hiking and chairlift but with neither visual movement nor physical exertion. Once the participant was ready, the portal showed a progress bar. Travel was possible once the bar was full. After the charging time elapsed, the participant could step through the portal at the foot of the mountain and they were instantly teleported to the platform at the top of the mountain.

3.2.4 Instant (Teleport). Finally, the instant condition used the same teleporter scene as the charging condition, but without the charging bar. This condition featured no exertion, no travel time, and no visual movement.

3.3 Measures and Analysis

Before the start of the experiment, we collected demographic data about the participants and information about their experience with VR. During the experiment, we administered a set of questionnaires after each condition.

We used the fast motion sickness scale introduced by Keshavarz et al. [25] throughout the study, which measures general discomfort with a special focus on nausea on a scale from zero to twenty.

As soon as the participant reached the top of the mountain and before they could recuperate, we displayed the Borg rating of perceived exertion (RPE) [6] to the participants. We then asked them to quickly rate a scale of *perceived exertion*. Participants were informed and reminded during each condition about the use of the Borg rating.

After the participants explored the scene on top of the mountain, we administered further questionnaires. To assess the sense of *presence* in the virtual scene, we used the IPQ Presence questionnaire [46, 47], which is the recommended presence questionnaire due to high reliability within a reasonable time frame. Further, we were interested in understanding if reaching the top of the mountain fostered a sense of pride or produced positive emotion. To that end, we administered the Positive and Negative Affect Schedule (PANAS [60]) to measure *positive emotion* and *negative emotion*. We also measured the *mental workload* experienced by the participants when completing the task using the NASA TLX [20]. Finally, we wanted to investigate if traveling in VR allowed users to enjoy a relaxing, mindful experience. Thus, we used the State Mindfulness Scale (SMS) by Tanay and Bernstein [55]. The SMS is a validated [43, 55] 21-item scale that has been used in numerous HCI studies [15, 52, 59]. We used all 21 items defined in the original publication [55].

All questionnaires except demographics were presented as an in-VR questionnaire on a virtual billboard alongside the platform atop the mountain. Past research indicates that in-VR questionnaires are preferable to asking users to exit the VR environment [48].

We used one-way within-subjects ANOVA procedures to analyze the differences between the conditions in our study. Post-hoc analyses were conducted using Tukey HSD. All reported p-values were adjusted using the Bonferroni-Holm method.

3.4 Apparatus

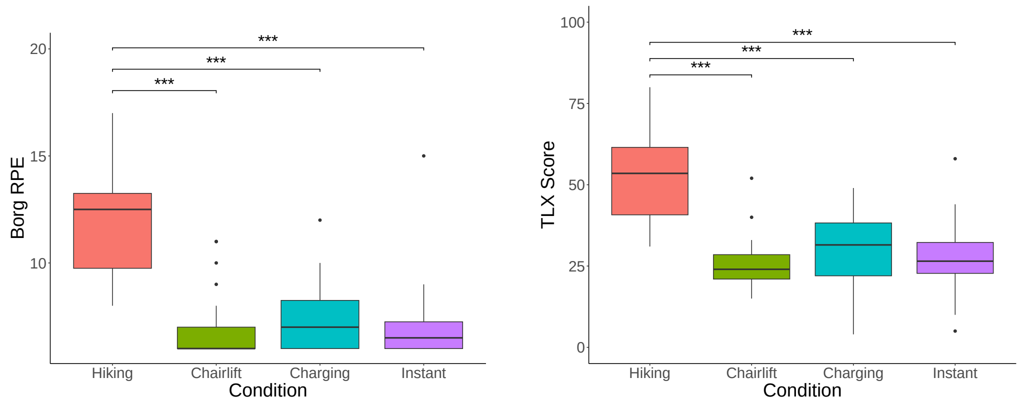
The scene was created with Unity3D. We used a Windows 10 PC with an Intel i7-8700, Nvidia RTX 2080, and 16GB RAM to run the VR environment. The scene was presented on an HTC VIVE Pro VR HMD. Further, we mounted an HTC VIVE tracker on the handle of a dog leash. The treadmill was an h/p/cosmos Saturn 300/100 r. The device has a walking area of $3m \times 1m$. Its intended use cases include walking, cycling, wheelchair movement, roller skating, and roller skiing. The treadmill uses an RS 232 serial interface for receiving commands from a PC, as well as and sending responses to specific queries. The device is equipped with a ceiling-mounted safety belt mechanism, which deactivates the treadmill in case of loss of control and prevents the user from falling off. Its maximum speed is $40km/h$ and the maximum incline is 27 percent (incline and decline). In the study, the treadmill was operated at a max speed of $1.1m/s$ ($3.96km/h$) and a maximum incline of 15 percent. The speed and incline were automatically set and adjusted from the unity scene via an interface included with the treadmill.

3.4.1 VR Scene. We built a custom VR scene to conduct our study. The scene featured an idyllic mountain landscape. The foot of the mountain was surrounded by trees, rocks, flowers, and grass. The users started their journey in a basin, and there was no way for the user to see far beyond this confined area. Thus, the scene was designed to make the user focus on the top of the mountain. Further, such a design implied that users would gradually discover more features of the environment as they traveled up the hill. The path to the top was completely straight. Its virtual size was mapped to the treadmill width. There were trees and rocks alongside the path. In all conditions, a dog lay down on the viewing platform in front of the user. We played ambient sounds as the users interacted with the scene, which included wind, birds chirping, and, in the case of the chairlift condition, chairlift noises and rattling whenever the chairlift passed an intermediate tower. The dog wiggled its ears when waiting for the start of the hike and changed its walking style depending on the walking speed.

3.5 Task and Procedure

A timeline of the study procedure is shown in Figure 2. After welcoming the participants, we introduced them to the system, the VR HMD, the treadmill, and corresponding security measures such as a security harness and emergency stop. We then obtained written consent for participation. Once the participants completed the demographics forms, we introduced them to the first assigned condition and corresponding task. Once the participants entered the VR scene, they could remain at the bottom of the mountain until they felt comfortable in the environment. When the participants declared that they were ready, we started the task.

When reaching the top of the mountain, the participants were asked to rate their exhaustion on the Borg scale. The participants then had one minute to enjoy the view atop the mountain, look around, and relax. After this phase, we asked them to look at a VR billboard and answer the



(a) Perceived Physical Exertion ratings on the Borg scale.

(b) Reported mental workload scores according to the NASA-TLX.

Fig. 5. Perceived Physical Exertion and Mental Workload across conditions. HIKING is significantly higher than all other conditions for both metrics.

questions corresponding to the remaining measures. If needed the participants could then take time to recuperate before continuing with the next condition. This procedure was repeated for each of the four conditions. After the last condition, we closed the session with a debriefing interview which asked about the users' perception of the different conditions and the emotions associated with each method of transportation. At the end of the study, the participants received compensation of EUR 15 and had the opportunity to ask questions.

4 RESULTS

In the following, we report the results for perceived exertion, mental workload, presence, emotions, and mindfulness.

4.1 Perceived Exertion

The HIKING condition was perceived as requiring significantly more effort than the other conditions. The ANOVA showed a significant effect of the condition on perceived physical exertion on the Borg scale, $F(3, 69) = 50.6$, $p < .001$, $\eta^2 = .69$. Post-hoc comparisons showed that HIKING ranked significantly higher than the other conditions, at the $p < .001$ level. There were no other significantly different pairs. Figure 5a visualizes the results.

4.2 Mental Workload

There was a significant effect of condition on the perceived mental workload on the NASA-TLX, $F(3, 69) = 33.24$, $p < .001$, $\eta^2 = .59$. The HIKING conditions resulted in significantly more reported mental workload than the other conditions, all at the $p < .001$ level. There were no other significantly different pairs of conditions. The results are shown in Figure 5b.

4.3 Presence

We also compared IPQ scores using a one-way ANOVA. There was a significant effect of the condition on perceived presence, $F(3, 69) = 3.96$, $p < .05$. There was only one significantly different pair of conditions—HIKING–CHARGING, at the $p < .05$ level. The results are presented in Figure 6.

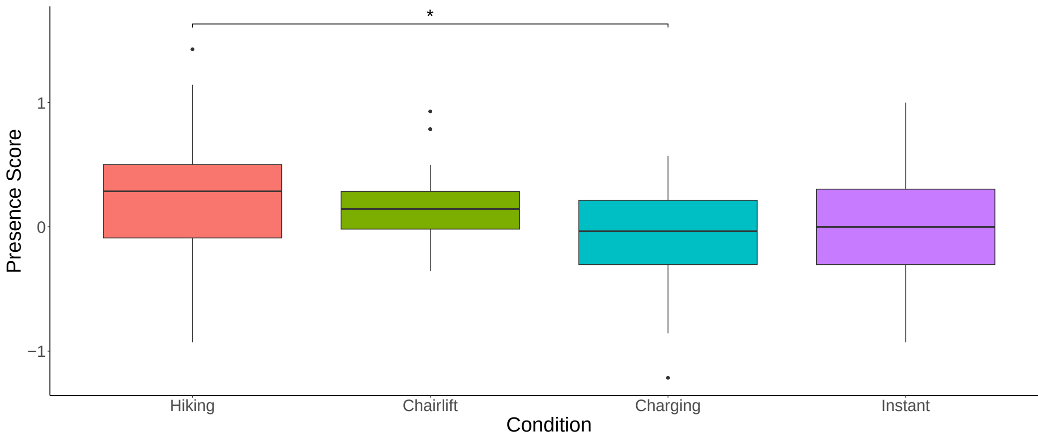


Fig. 6. Presence across conditions measured using the IPQ. Hiking is significantly higher than Charging

4.4 Positive Emotion

Our analysis revealed that the was a significant effect of the mode of transport (condition) on reported positive emotions according to the PANAS-P, $F(3, 69) = 13.31$, $p < .001$, $\eta^2 = .15$. As shown in Figure 7a, HIKING outperformed the other conditions and scored significantly higher than CHAIRLIFT ($p < .05$), CHARGING ($p < .01$) and INSTANT ($p < .05$).

4.5 Negative Emotion

A one-way ANOVA showed that there was no effect of condition on reported levels of negative emotion on the PANAS-N, $F(3, 69) = 0.15$, $p = .15$.

4.6 Mindfulness

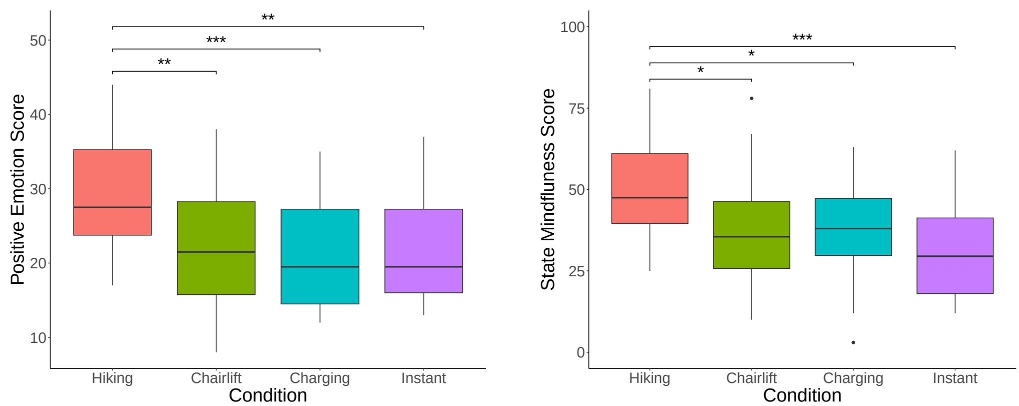
Finally, we analyzed the scores on the SMS, as shown in Figure 7b. A one-way ANOVA showed a significant effect, $F(3, 69) = 12.22$, $p < .001$, $\eta^2 = .35$. The HIKING condition led to more reported mindfulness than the other conditions. There were significant post-hoc differences between HIKING and CHAIRLIFT ($p < .05$), CHARGING ($p < .05$) and INSTANT ($p < .01$).

5 DISCUSSION

We conducted this investigation to understand how physical exertion changes the way users experience a virtual scene (RQ1), specifically seeking to understand if we can replicate the wellbeing benefits of hiking in VR (RQ1a) and whether physical exertion in VR increases users' wellbeing (RQ1b). In the following, we will discuss these research questions, outline how our results can be used to inform the design of future VR experiences, and note the limitations of our work.

5.1 Hiking in VR was perceived as requiring physical exertion similar to hiking in real-life

To answer RQ1a, we aimed to verify that physical exertion was caused by the physical demands of walking (TREADMILL), and not by visual movement in the scene (CHAIRLIFT) or by time (CHARGING) only. Our results, see Figure 5, show that the physical exertion and effort are significantly higher for HIKING compared to all other conditions (CHAIRLIFT, CHARGING, and INSTANT). This is shown by both the Borg-scale (Figure 5a) and NASA-TLX (Figure 5b)). These findings suggest that carefully



(a) Positive emotions across conditions according to the PANAS-P.

(b) State mindfulness across conditions measured using the SMS.

Fig. 7. Positive emotions and mindfulness scores across conditions. Hiking is significantly higher than all other conditions for both metrics.

designed experiences have the potential to effectively mimic exertion similar to activities in real life. As a consequence, future VR systems should consider using exertion interfaces as possible design alternatives for engaging VR experiences.

5.2 Active locomotion in VR fostered a mindful experience and produced positive emotions

Both the ratings for PANAS-P and SMS were significantly higher for hiking than for the other conditions (RQ1b), implying that hiking produced more positive emotions and was perceived as more mindful. This result implies that past research suggesting a connection between mindfulness and an experience of meaning can also be applied to VR [44], along with findings showing that low-intensity exercise can induce mindfulness [38]. Furthermore, this supports recent work suggesting that exercise in VR leads to more positive emotions [34, 45]. Combined, our findings show that physical exertion and locomotion are effective means for designing mindful experiences in virtual reality. We hypothesize that the need to invest effort in hiking up the mountain made the locomotion experience more meaningful to the users, thus contributing to a significantly higher perception of mindfulness.

Further, our results are in line with prior work showing that users enjoy exercising in VR while resulting in more exertion [37] and that participants experience less pain while exercising in VR [32]. Past work has also shown that perceived exhaustion can be manipulated by changing virtual representations [33].

The time of exposure to the environment also plays a role in this phenomenon. While we designed all conditions other than instant to have the same time of exposure of 4.5 minutes, both Borg and NASA-TLX were significantly higher for hiking. Our results, therefore, suggest that visual exposure and movement through the virtual world may not play a significant role in fostering mindfulness or positive emotions.

5.3 Designers can use physical exertion in VR to create meaningful experiences

We argue that physical exertion helped users to be more mindful of the scene and experience. Both PANAS and SMS showed to be significantly higher for HIKING than the other conditions. Therefore, this can help to create more mentally healthy experiences. While VR scenes are often designed to optimize interaction efficiency, our work highlights the potential for intentionally designing physically demanding tasks. Therefore, adding design elements that increase perceived exertion to a virtual scene or technical setup can make a virtual experience more meaningful. This represents a design opportunity for haptic feedback devices to add meaning to scenes by making feedback more exhausting. Achieving the goal of a physically demanding task can lead to a feeling of pride and therefore make a virtual scene more rewarding.

5.4 There is preliminary evidence that locomotion in VR increases presence

Neither exposure time, visual movement, nor physical exertion had an effect on presence in our study. This is in line with the definition of presence by Slater et al. [50], as the scene in our study did not change and being involved and excited is to be separated from the feeling of "being there". However, previous work shows unclear conclusions relating to the effect of locomotion techniques on presence. Slater et al. [51] found that walking could enhance presence ratings when participants embodied the presented avatar. Conversely, past work on gaming with omnidirectional treadmills [61] and on exergaming [7, 13] found no impact of exertion on presence.

Usoh et al. [57] reported that their participants felt higher levels of presence when walking-in-place compared to flying and controlling the flight with button presses. However, unlike locomotion techniques where one can "walk" forward by pressing forward on a controller, CHAIRLIFT did not include any locomotion of the participant that is not reflected in the virtual world and therefore did not create a break in presence (such as the avatar walking while not walking in real-life). Further, we did not present a virtual body to the participants; they held a physical dog leash and saw the leash rendered based on the movement of the tracker attached to it. This could be perceived as part of the participant's body. This design choice built a connection to the dog and a form of extension to the user's body.

The presence score is significantly lower for CHARGING when compared to HIKING. We hypothesize that this difference was caused by the need to wait for the teleporter to charge. While waiting, the participants could intensively look around and notice any rendering issues, repeating textures, etc., which could break the immersion and would go unnoticed otherwise.

These results can impact future design choices for VR experiences. Streaming, a mechanic often used in Open World games, is a way to load adjacent world elements and therefore allow users to walk or drive into new areas without interruption. However, when fast-traveling to distant areas, the player is often prompted with a loading screen. In multiplayer games, the player often needs to wait in a lobby or watch a loading screen until enough players are found and connected and the game is synchronized among them. Therefore, in cases were loading times are necessary, designers should consider letting players either visually transit into the desired area by, for example, riding a chairlift, cab, or horse carriage. Ideally, the player should be able to walk to the desired location.

5.5 Designing VR experiences with mindfulness and relaxation

Although our study focused on investigating how exertion impacts VR experiences, our findings also have implications for the wider health and wellbeing communities. In particular, prior research has shown that VR can be a useful tool to support mindfulness practices [49]. This could also be extended to the workplace, where people often experience stress in their daily routines [14]. There is a need to design new ways to release stress and create healthier workplaces [18] which cater to diverse populations. While going to a remote place, strolling through a forest, or hiking up a mountain are well-known activities that relieve stress, they are not always readily available. Depending on the location, finding such a place or activity to relax may not even be impossible. As VR hardware becomes more ubiquitous, there is an opportunity for VR to offer experiences of mindfulness in everyday life and enable users to take breaks from work in virtual locations. VR systems can offer physically demanding activities that bring a sense of achievement and pride. Further, our results shows that exertion VR may be a useful tool in mindfulness-oriented physical activity programs [40]. Future studies should further investigate the potential for such systems, as our work provides empirical support to show that locomotion is a particularly important design aspect for VR systems that support mental wellbeing.

5.6 Limitations

While we conducted the study in this paper with the utmost care, we recognize that our research has some limitations. First, there are potential limitations related to the internal characteristics of the participants. We did not investigate the effect of different fitness levels as we did not measure the effect of performance but, rather, if a heightened level of exertion was achieved during the HIKING condition. While using a treadmill proved to be an effective way of generating higher levels of exertion, results might be limited to the reflected task of walking up a mountain and not to other activities with high exertion.

Second, there are several limitations associated with the study apparatus. We played background noises, such as wind sounds and birds chirping, during all conditions. While we did this primarily to create a more engaging scene, this was also done to mask any treadmill sounds. While none of the participants mentioned that they noticed any vibration or sounds, it is possible that this could have had a confounding impact on the experience. Further, it is unclear if the design and look of the nature scene can have an impact on mindfulness. However, all conditions use the same environmental design while two conditions also reflect real-life activities with the same level of visual exposure (HIKING, CHAIRLIFT) as they would have in a real-life nature scenario. In the HIKING condition, participants could signal if a decrease in the treadmill speed was needed. Otherwise, the speed was set, and took 4.5*min* to reach the top. Therefore, we do not have any insight as to how variable walking speed impacts the ratings, as the set speed created the illusion of getting pulled by the dog.

Finally, there are limitations relating to the virtual representation of the participants. The participants in our study were immersed in an interactive virtual scene, but we did not present them with any form of a virtual body. Previous research has shown that an avatar representation affects the way we behave [26] or perceive ourselves [54]. While the impact of the lack of a virtual representation on our results is unclear, it also creates an opportunity for future work. There is a need to study how different avatars and levels of embodiment affect the experience of locomotion in VR. Avatars and other virtual representations such as step sounds [21, 26] could be used to cause an increase in perceived exertion and therefore decrease needed time or increase effects.

6 CONCLUSION

VR enables users to go to remote places with the click of a button. Yet, when traveling in the real world, the journey is often described as more important than reaching the destination. To investigate if similar experiences are possible in VR, we studied the impact of different travel methods in VR on the users' perceptions. We built a virtual scene in the form of a path up a mountain toward a viewing platform that looked over a beautiful valley. The participants used four ways to reach the mountaintop, designed to differ in physical exertion, travel time, and visual exposure to movement in the scene. Participants hiked up a slope using a treadmill, sat on a chairlift, used a teleporter after waiting for it to charge, and used an instant teleporter.

Our results show that hiking was more exhausting, fostered more mindfulness, and produced more positive emotions than the other transportation methods. We provide empirical evidence that it is possible to foster a state of mindfulness through walking in VR. This suggests that introducing physical exertion to VR scenes can be a means of using VR for relaxation. Further, our findings suggest that exhaustion through locomotion can be an effective design element for VR, which can be used to enhance the way users experience environments. Locomotion and exhaustion make the scene more meaningful and the person immersed in the scene more aware of themselves and their surroundings. This, in turn, can be used as a starting point for designing systems that support the users' wellbeing. We hope that our work inspires future research on using locomotion in VR for user benefit.

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REFERENCES

[1] Aino Ahtinen, Eeva Andrejeff, Christopher Harris, and Kaisa Väänänen. 2017. Let's walk at work: persuasion through the brainwolk walking meeting app. In *Proceedings of the 21st International Academic Mindtrek Conference on - AcademicMindtrek '17*. ACM Press, Tampere, Finland, 73–82. https://doi.org/10.1145/3131085.3131098

[2] A. Ahtinen, E. Andrejeff, M. Vuolle, and K. Väänänen. 2016. Walk as You Work: User Study and Design Implications for Mobile Walking Meetings. In *NordiCHI '16: Proceedings of the 9th Nordic Conference on Human-Computer Interaction*. ACM, Gothenburg, Sweden, 1–10. https://doi.org/10.1145/2971485.2971510

[3] Aino Ahtinen, Eeva Andrejeff, and Kaisa Väänänen. 2016. Brainwolk: a mobile technology mediated walking meeting concept for wellbeing and creativity at work. In *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia (MUM '16)*. Association for Computing Machinery, Rovaniemi, Finland, 307–309. https://doi.org/10.1145/3012709.3016062

[4] Marcelo Bigliassi, Bruno M Galano, Adriano E Lima-Silva, and Romulo Bertuzzi. 2020. Effects of mindfulness on psychological and psychophysiological responses during self-paced walking. *Psychophysiology* 57, 4 (2020), e13529.

[5] John Bolton, Mike Lambert, Denis Lirette, and Ben Unsworth. 2014. PaperDude: a virtual reality cycling exergame. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems (CHI EA '14)*. Association for Computing Machinery, New York, NY, USA, 475–478. https://doi.org/10.1145/2559206.2574827

[6] Gunnar a. V. Borg. 1982. Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise* 14, 5 (1982), 377–381. https://journals.lww.com/acsm-msse/Abstract/1982/05000/Psychophysical_bases_of_perceived_exertion.12.aspx

[7] Felix Born, Sophie Abramowski, and Maic Masuch. 2019. Exergaming in VR: The Impact of Immersive Embodiment on Motivation, Performance, and Perceived Exertion. 1–8. https://doi.org/10.1109/VS-Games.2019.8864579 ISSN: 2474-0489.

[8] James V. Bradley. 1958. Complete Counterbalancing of Immediate Sequential Effects in a Latin Square Design. *J. Amer. Statist. Assoc.* 53, 282 (June 1958), 525–528. https://doi.org/10.1080/01621459.1958.10501456 Publisher: Taylor & Francis _eprint: https://www.tandfonline.com/doi/pdf/10.1080/01621459.1958.10501456.

[9] Martina Caramenti, Claudio L. Lafortuna, Elena Mugellini, Omar Abou Khaled, Jean-Pierre Bresciani, and Amandine Dubois. 2018. Matching optical flow to motor speed in virtual reality while running on a treadmill. *PLoS ONE* 13, 4 (Jan. 2018), e0195781. https://doi.org/10.1371/journal.pone.0195781

[10] Anne A. Cuperus, Anouk Keizer, Andrea W. M. Evers, Marijn M. L. van den Houten, Joep A. W. Teijink, and Ineke J. M. van der Ham. 2018. Manipulating spatial distance in virtual reality: Effects on treadmill walking performance in patients with intermittent claudication. *Computers in Human Behavior* 79 (Feb. 2018), 211–216. https://doi.org/10.1016/j.chb.2017.10.037

[11] Ida Damen, Carine Lallemand, Rens Brankaert, Aarnout Brombacher, Pieter van Wesemael, and Steven Vos. 2020. *Understanding Walking Meetings: Drivers and Barriers*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376141

[12] Xiaoyan Deng, H. Rao Unnava, and Hyojin Lee. 2019. "Too true to be good?" when virtual reality decreases interest in actual reality. *Journal of Business Research* 100 (July 2019), 561–570. https://doi.org/10.1016/j.jbusres.2018.11.008

[13] Dennis Dietz, Carl Oechsner, Changkun Ou, Francesco Chiossi, Fabio Sarto, Sven Mayer, and Andreas Butz. 2022. Walk This Beam: Impact of Different Balance Assistance Strategies and Height Exposure on Performance and Physiological Arousal in VR. In *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology* (Tsukuba, Japan) *(VRST '22)*. Association for Computing Machinery, New York, NY, USA, Article 32, 12 pages. https://doi.org/10.1145/3562939.3567818

[14] Xianghua (Sharon) Ding, Shuhan Wei, Xinning Gui, Ning Gu, and Peng Zhang. 2021. *Data Engagement Reconsidered: A Study of Automatic Stress Tracking Technology in Use.* Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3411764.3445763

[15] Nina Döllinger, Erik Wolf, David Mal, Nico Erdmannsdörfer, Mario Botsch, Marc Erich Latoschik, and Carolin Wienrich. 2022. Virtual Reality for Mind and Body: Does the Sense of Embodiment Towards a Virtual Body Affect Physical Body Awareness?. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems (CHI EA '22)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3491101.3519613

[16] J. E. Giphart, Y.-H. Chou, D. H. Kim, C. T. Bortnyk, and R. C. Wagenaar. 2007. Effects of Virtual Reality Immersion and Walking Speed on Coordination of Arm and Leg Movements. *Presence: Teleoperators & Virtual Environments* 16, 4 (Aug. 2007), 399–413. https://doi.org/10.1162/pres.16.4.399

[17] Luke Haliburton, Natalia Bartłomiejczyk, Paweł Woźniak, Albrecht Schmidt, and Jasmin Niess. 2023. The Walking Talking Stick: Understanding Automated Note-Taking in Walking Meetings. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, Hamburg, Germany, 16. https://doi.org/10.1145/3544548.3580986

[18] Luke Haliburton and Albrecht Schmidt. 2020. Technologies for healthy work. *Interactions* 27, 3 (April 2020), 64–66. https://doi.org/10.1145/3386391

[19] Luke Haliburton, Pawel W. Wozniak, Albrecht Schmidt, and Jasmin Niess. 2021. Charting the Path: Requirements and Constraints for Technology-Supported Walking Meetings. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW2 (Oct. 2021), 347:1–347:31. https://doi.org/10.1145/3476088

[20] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[21] Matthias Hoppe, Jakob Karolus, Felix Dietz, Paweł W Woźniak, Albrecht Schmidt, and Tonja-Katrin Machulla. 2019. Vrsneaky: Increasing presence in vr through gait-aware auditory feedback. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–9.

[22] Matthias Hoppe, Beat Rossmy, Daniel Peter Neumann, Stephan Streuber, Albrecht Schmidt, and Tonja-Katrin Machulla. 2020. A Human Touch: Social Touch Increases the Perceived Human-likeness of Agents in Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3313831.3376719

[23] Florian Hruby. 2019. The Sound of Being There: Audiovisual Cartography with Immersive Virtual Environments. *KN - Journal of Cartography and Geographic Information* 69, 1 (May 2019), 19–28. https://doi.org/10.1007/s42489-019-00003-5

[24] Jon Kabat-Zinn. 2015. Mindfulness. *Mindfulness* 6, 6 (2015), 1481–1483.

[25] Behrang Keshavarz and Heiko Hecht. 2011. Validating an efficient method to quantify motion sickness. *Human Factors* 53, 4 (2011), 415–426.

[26] Konstantina Kilteni, Ilias Bergstrom, and Mel Slater. 2013. Drumming in immersive virtual reality: the body shapes the way we play. *IEEE transactions on visualization and computer graphics* 19, 4 (2013), 597–605.

[27] Junho Ko, Seong-Wook Jang, Hyo Taek Lee, Han-Kyung Yun, and Yoon Sang Kim. 2020. Effects of Virtual Reality and Non–Virtual Reality Exercises on the Exercise Capacity and Concentration of Users in a Ski Exergame: Comparative Study. *JMIR Serious Games* 8, 4 (Oct. 2020), e16693. https://doi.org/10.2196/16693 Company: JMIR Serious Games Distributor: JMIR Serious Games Institution: JMIR Serious Games Label: JMIR Serious Games Publisher: JMIR Publications Inc., Toronto, Canada.

[28] Felix Kosmalla, André Zenner, Marco Speicher, Florian Daiber, Nico Herbig, and Antonio Krüger. 2017. Exploring Rock Climbing in Mixed Reality Environments. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '17*. ACM Press, Denver, Colorado, USA, 1787–1793. https://doi.org/10.1145/3027063.3053110

[29] S. J. Lackey, J. N. Salcedo, J.L. Szalma, and P.A. Hancock. 2016. The stress and workload of virtual reality training: the effects of presence, immersion and flow. *Ergonomics* 59, 8 (Aug. 2016), 1060–1072. https://doi.org/10.1080/00140139.2015.1122234

[30] Seth LaJeunesse and Daniel A Rodríguez. 2012. Mindfulness, time affluence, and journey-based affect: exploring relationships. *Transportation research part F: traffic psychology and behaviour* 15, 2 (2012), 196–205.

[31] Daniel Levi and Sara Kocher. 1999. Virtual Nature: The Future Effects of Information Technology on Our Relationship to Nature. *Environment and Behavior* 31, 2 (March 1999), 203–226. https://doi.org/10.1177/00139169921972065

[32] Maria Matsangidou, Chee Siang Ang, Alexis R. Mauger, Jittrapol Intarasirisawat, Boris Otkhmezuri, and Marios N. Avraamides. 2019. Is your virtual self as sensational as your real? Virtual Reality: The effect of body consciousness on the experience of exercise sensations. *Psychology of Sport and Exercise* 41 (March 2019), 218–224. https://doi.org/10.1016/j.psychsport.2018.07.004

[33] Maria Matsangidou, Chee Siang Ang, Alexis R. Mauger, Boris Otkhmezuri, and Luma Tabbaa. 2017. How Real Is Unreal?. In *Human-Computer Interaction – INTERACT 2017 (Lecture Notes in Computer Science)*, Regina Bernhaupt, Girish Dalvi, Anirudha Joshi, Devanuj K. Balkrishan, Jacki O'Neill, and Marco Winckler (Eds.). Springer International Publishing, Cham, 273–288. https://doi.org/10.1007/978-3-319-68059-0_18

[34] Maria Matsangidou, Fotos Frangoudes, Marios Hadjiaros, Eirini Schiza, Kleanthis C. Neokleous, Ersi Papayianni, Marios Avraamides, and Constantinos S. Pattichis. 2022. "Bring me sunshine, bring me (physical) strength": The case of dementia. Designing and implementing a virtual reality system for physical training during the COVID-19 pandemic. *International Journal of Human-Computer Studies* 165 (Sept. 2022), 102840. https://doi.org/10.1016/j.ijhcs.2022.102840

[35] Maria Matsangidou, Alexis R. Mauger, Chee Siang Ang, and Constantinos S. Pattichis. 2020. Sampling Electrocardiography Confirmation for a Virtual Reality Pain Management Tool. In *Virtual, Augmented and Mixed Reality. Industrial and Everyday Life Applications (Lecture Notes in Computer Science)*, Jessie Y. C. Chen and Gino Fragomeni (Eds.). Springer International Publishing, Cham, 399–414. https://doi.org/10.1007/978-3-030-49698-2_27

[36] Paul Milgram and Fumio Kishino. 1994. A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems* E77-D, 12 (Dec. 1994), 16.

[37] Edward G. Murray, David L. Neumann, Robyn L. Moffitt, and Patrick R. Thomas. 2016. The effects of the presence of others during a rowing exercise in a virtual reality environment. *Psychology of Sport and Exercise* 22 (Jan. 2016), 328–336. https://doi.org/10.1016/j.psychsport.2015.09.007

[38] Yael Netz and Ronnie Lidor. 2003. Mood alterations in mindful versus aerobic exercise modes. *The Journal of psychology* 137, 5 (2003), 405–419.

[39] Ryan Niemiec, Tayyab Rashid, and Marcello Spinella. 2012. Strong mindfulness: Integrating mindfulness and character strengths. *Journal of Mental Health Counseling* 34, 3 (2012), 240–253.

[40] Peter Nymberg, Susanna Calling, Emelie Stenman, Karolina Palmér, Eva Ekvall Hansson, Kristina Sundquist, Jan Sundquist, and Bengt Zöller. 2021. Effect of mindfulness on physical activity in primary healthcare patients: a randomised controlled trial pilot study. *Pilot and feasibility studies* 7, 1 (2021), 1–14.

[41] Kati Orru, Sergey Kask, and Annika Nordlund. 2019. Satisfaction with virtual nature tour: the roles of the need for emotional arousal and pro-ecological motivations. *Journal of Ecotourism* 18, 3 (July 2019), 221–242. https://doi.org/10.1080/14724049.2018.1526290

[42] Adrian Reetz, Deltcho Valtchanov, Michael Barnett-Cowan, Mark Hancock, and James R. Wallace. 2021. Nature vs. Stress: Investigating the Use of Biophilia in Non-Violent Exploration Games to Reduce Stress. *Proceedings of the ACM on Human-Computer Interaction* 5, CHI PLAY (Oct. 2021), 247:1–247:13. https://doi.org/10.1145/3474674

[43] Liad Ruimi, Yuval Hadash, Galia Tanay, and Amit Bernstein. 2022. State Mindfulness Scale (SMS). In *Handbook of Assessment in Mindfulness Research*, Oleg N. Medvedev, Christian U. Krägeloh, Richard J. Siegert, and Nirbhay N. Singh (Eds.). Springer International Publishing, Cham, 1–16. https://doi.org/10.1007/978-3-030-77644-2_25-1

[44] Richard M Ryan, Veronika Huta, and Edward L Deci. 2008. Living well: A self-determination theory perspective on eudaimonia. *Journal of happiness studies* 9, 1 (2008), 139–170.

[45] Pablo Saiz-González, Daniel McDonough, Wenxi Liu, and Zan Gao. 2023. Acute Effects of Virtual Reality Exercise on Young Adults' Blood Pressure and Feelings. *International Journal of Mental Health Promotion* (Feb. 2023). https://doi.org/10.32604/ijmhp.2023.027530

[46] Thomas Schubert. 2003. The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. *Zeitschrift für Medienpsychologie* 15 (April 2003), 69–71. https://doi.org/10.1026//1617-6383.15.2.69

[47] Thomas Schubert, Frank Friedmann, and Holger Regenbrecht. 2001. The Experience of Presence: Factor Analytic Insights. *PRESENCE: Teleoperators & Virtual Environments* 10, 3 (June 2001), 266–281. https://doi.org/10.1162/105474601300343603 Publisher: MIT Press.

[48] Valentin Schwind, Pascal Knierim, Nico Haas, and Niels Henze. 2019. Using Presence Questionnaires in Virtual Reality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*. ACM Press, Glasgow, Scotland Uk, 1–12. https://doi.org/10.1145/3290605.3300590

[49] Elizabeth Seabrook, Ryan Kelly, Fiona Foley, Stephen Theiler, Neil Thomas, Greg Wadley, and Maja Nedeljkovic. 2020. Understanding How Virtual Reality Can Support Mindfulness Practice: Mixed Methods Study. *Journal of Medical Internet Research* 22, 3 (March 2020), e16106. https://doi.org/10.2196/16106

[50] Mel Slater. 2003. A note on presence terminology. *Presence connect* 3, 3 (2003), 1–5.

[51] Mel Slater, Martin Usoh, and Anthony Steed. 1995. Taking steps: the influence of a walking technique on presence in virtual reality. *ACM Transactions on Computer-Human Interaction (TOCHI)* 2, 3 (1995), 201–219.

[52] Jacek Sliwinski, Mary Katsikitis, and Christian Martyn Jones. 2018. Designing and Evaluating Games for Mindfulness. *Computers in Entertainment* 16, 3 (Sept. 2018), 5:1–5:15. https://doi.org/10.1145/3236496

[53] L. H. Sloot, M. M. van der Krogt, and J. Harlaar. 2014. Effects of adding a virtual reality environment to different modes of treadmill walking. *Gait & Posture* 39, 3 (March 2014), 939–945. https://doi.org/10.1016/j.gaitpost.2013.12.005

[54] Ana Tajadura-Jiménez, Maria Basia, Ophelia Deroy, Merle Fairhurst, Nicolai Marquardt, and Nadia Bianchi-Berthouze. 2015. As light as your footsteps: altering walking sounds to change perceived body weight, emotional state and gait. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems*. 2943–2952.

[55] Galia Tanay and Amit Bernstein. 2013. State Mindfulness Scale (SMS): Development and initial validation. *Psychological Assessment* 25, 4 (2013), 1286–1299. https://doi.org/10.1037/a0034044

[56] Nađa Terzimehić, Renate Häuslschmid, Heinrich Hussmann, and m.c. schraefel. 2019. A Review & Analysis of Mindfulness Research in HCI: Framing Current Lines of Research and Future Opportunities. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300687

[57] Martin Usoh, Kevin Arthur, Mary C Whitton, Rui Bastos, Anthony Steed, Mel Slater, and Frederick P Brooks Jr. 1999. Walking> walking-in-place> flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*. 359–364.

[58] Deltcho Valtchanov, Kevin R. Barton, and Colin Ellard. 2010. Restorative Effects of Virtual Nature Settings. *Cyberpsychology, Behavior, and Social Networking* 13, 5 (Oct. 2010), 503–512. https://doi.org/10.1089/cyber.2009.0308 Publisher: Mary Ann Liebert, Inc., publishers.

[59] Nadine Wagener, Alex Ackermann, Gian-Luca Savino, Bastian Dänekas, Jasmin Niess, and Johannes Schöning. 2022. Influence of Passive Haptic and Auditory Feedback on Presence and Mindfulness in Virtual Reality Environments. In *Proceedings of the 2022 International Conference on Multimodal Interaction (ICMI '22)*. Association for Computing Machinery, New York, NY, USA, 558–569. https://doi.org/10.1145/3536221.3556622

[60] David Watson, Lee Anna Clark, and Auke Tellegen. 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology* 54, 6 (1988), 1063.

[61] Lars-Ole Wehden, Felix Reer, Robin Janzik, Wai Yen Tang, and Thorsten Quandt. 2021. The Slippery Path to Total Presence: How Omnidirectional Virtual Reality Treadmills Influence the Gaming Experience. *Media and Communication* 9, 1 (Jan. 2021), 5–16. https://www.cogitatiopress.com/mediaandcommunication/article/view/3170

[62] Edward O. Wilson. 2021. *Biophilia*. Harvard University Press. https://doi.org/10.4159/9780674045231 Publication Title: Biophilia.

[63] Soojeong Yoo and Judy Kay. 2016. VRun: running-in-place virtual reality exergame. In *Proceedings of the 28th Australian Conference on Computer-Human Interaction (OzCHI '16)*. Association for Computing Machinery, New York, NY, USA, 562–566. https://doi.org/10.1145/3010915.3010987

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