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Immersion and Presence in Virtual Nature: How Does the Delivery Technology Affect the Psychological Immersion, Presence, and Virtual Reality Sickness in Virtual Nature?

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ABSTRACT
Virtual nature exposure can support wellbeing and health, but outcomes may vary by delivery technology. This study investigates how the delivery technology affects psychological immersion, presence, and VR-sickness symptoms in virtual nature. Three different technologies for delivering virtual nature were compared: TV, VR-headset, and virtual nature room. In a three-condition randomized trial with a crossover design, 62 participants visited once in each condition for a 15-minute exposure. Generally, participants' psychological immersion and presence outcomes were higher in the VR headset and virtual nature room conditions than in the TV condition. Psychological immersion and presence outcomes were higher in the VR headset condition than in the virtual nature room condition. In terms of VR sickness, there were some interesting findings depending on the measured subscale (oculomotor and disorientation). We also unpack and provide an exemplar on how to use the terms technological immersion, psychological immersion, and presence in virtual environment research.

KEYWORDS
Virtual nature; virtual forest; virtual reality; immersion; presence

1. Introduction

Benefits of nature exposure on public health are widely asserted (cf. Dadvand et al., 2023; Hartig et al., 2014; Konijnendijk et al., 2023; Nejade et al., 2022), but as factors like nature loss, urbanization, and modern lifestyles spent mainly indoors have decreased the opportunities to visit actual nature, it is important to offer and research alternative means to provide nature exposure indoors.

In contrast, technological advancements and innovations have facilitated the design and development of new virtual concepts, which provide a wide variety of possibilities to immerse their users to different virtual environments. One such concept that has greatly benefited from the recent technological advancement is virtual nature. Virtual nature refers to solutions where a nature environment is delivered by utilizing digital technology. Virtual nature exposure can be defined as digitally mediated, multisensory experiences designed to reproduce selected perceptual, cognitive, affective, and physiological functions of natural environments, aiming at delivering immersive experiences with measurable health or wellbeing outcomes. Virtual nature's effectiveness is typically defined by the ability to trigger sensory engagement and psychological immersion in order to capture nature–health mechanisms such as stress reduction (Ulrich, 1983; Ulrich et al., 1991) and attentional restoration (Kaplan & Kaplan, 1989) in diverse user contexts (Frost et al., 2022).

Virtual nature environments are intended to supplement, not replace, direct experiences of actual nature, particularly in contexts where access is limited. In consequence, virtual nature environments are increasingly used in workplaces, educational facilities, hospitals, elderly care homes, and in other settings where actual nature is not available. Thus, virtual nature can serve various types of user groups.

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The most popular technologies for delivering virtual nature are different screens, projectors, and virtual reality (VR) headsets (cf. Browning et al., 2021). Typical content includes panoramic or 360-degree photos and videos, computer-generated imagery, and sounds. In addition to visual and auditory stimuli, olfactory, haptic, and thermal stimuli can also be used, but their use has been less common (Nukarinen et al., 2022). Different delivery technologies with varying technological immersion can provide varying levels of realism, interactivity, psychological immersion, and presence, which ultimately translates into the capability of the delivery technology to produce relatively similar benefits in virtual nature as exposure to actual nature does (Litleskare et al., 2020).

Considerable number of research has demonstrated that virtual nature can provide similar type of experiences and psychophysiological benefits than actual nature (e.g., Browning et al., 2019; Nukarinen et al., 2020; Ojala et al., 2022; Reese et al., 2022; Takayama et al., 2022). Related systematic reviews generally demonstrate positive outcomes on restoration, stress levels, and affect, for example (cf. Frost et al., 2022; Li et al., 2023; Spano et al., 2023). Furthermore, virtual nature has been shown to have potential in promoting nature connectedness (e.g., Brambilla et al., 2024; Calogiuri et al., 2025; Leung et al., 2022; Sneed et al., 2021). Studies have also compared different delivery technologies' effectiveness in promoting psychophysiological benefits. We discuss this further in Section 2.1.

Importantly, research has also suggested that immersion and presence work as key factors in facilitating the psychophysiological benefits of virtual nature (Bolouki et al., 2025, Litleskare et al., 2020) and are also key determinants of enjoyable and effective experience (Lurdes Calisto & Sarkar, 2024). On the other hand, some studies suggest that the occurrence of VR sickness symptoms could reduce these same benefits (Calogiuri et al., 2017; Litleskare et al., 2020). Hence, identifying how to support psychological immersion and presence and how to avoid VR sickness is important not only for the overall experience but also for the associated benefits. As a mediator of the experience, the delivery technology plays a significant role in this. There is, however, limited research and lack of understanding on the propensity of different delivery technologies to induce presence, psychological immersion, and VR sickness symptoms in virtual nature (e.g., Frost et al., 2022) and which delivery technology provides the best combination of these core determinants (Spano et al., 2023).

To address this gap, the purpose of this study is to increase the understanding on how the used delivery technology affects these three core determinants of high-quality experience: psychological immersion, presence, and VR sickness symptoms in virtual nature. The specific focus is on comparing three different technologies with varying technological immersion for delivering virtual nature: 75″ TV (low), virtual nature room (medium), and VR headset (high technological immersion). Using the same virtual nature material with different technologies enables a genuine comparison of these technologies and allows to draw conclusions about the propensities of the technologies and, ultimately, about which delivery technology should be used. The main research questions are: (1) How do different delivery technologies vary in their effectiveness in inducing psychological immersion and sense of presence in virtual nature? and (2) How does the used delivery technology influence the experienced VR sickness in virtual nature?

2. Background

2.1. Immersion and presence in the context of virtual nature

Virtual nature can be seen as a form of communication between the environment and the viewer conveyed through different media. All the technologies used in our study (TV screen, virtual nature room, and VR headset) can be understood as communication mediums in the broader sense of transmitting information from a creator to a viewer. Due to their technological differences and level of technological immersion, they also vary in their capability of transmitting this information and sensory stimulation, potentially affecting presence and psychological immersion.

Virtual environments and experiences (which ever kind they may be) are often classified under different *realities*, such as mixed reality, virtual reality, augmented reality, extended reality, digital reality, or similar (cf. Rauschnabel et al., 2022). For years, there has been an ongoing ambiguity regarding the use of these terms with different "prototypical views" rooting for varying ways to define these new digitally mediated reality formats, subsequently leading to "an inconsistent and incomplete use of new reality terminology" (Rauschnabel et al., 2022) and a lack of shared understanding of these terms (Laato et al., 2024). For example, virtual reality is often conceptualized as a medium within the umbrella concept of extended reality, but not always (Rauschnabel et al., 2022). As the conceptualization of different realities falls outside the scope of this study, we do not address it here further. Nevertheless, across digitally mediated realities, immersion and presence are consistently identified as the central aspects of the experience (e.g., Laato et al., 2024).

Immersion is a central component of virtual environments and can be defined from two perspectives: technological and psychological. Technological immersion, meaning immersion as a property of a technology, refers to the extent the technology is capable of delivering an inclusive and extensive surrounding and a vivid illusion of reality to the senses of a human participant (Slater & Wilbur, 1997). In this definition, Inclusive denotes "the extent to which physical reality is shut out"; Extensive denotes "the range of sensory modalities accommodated"; Surrounding denotes "the extent to which this virtual reality is panoramic rather than limited to a narrow field"; and Vivid denotes "the resolution, fidelity, and variety of energy simulated within a particular modality" (Slater & Wilbur, 1997, p. 3). Considering the large number of different technologies and modalities, classifying different technologies based on their technological immersion can be ambiguous. Li et al. (2023) suggested a classification for virtual nature delivery technologies by their technological immersion. They classified these technologies into low (e.g., TV screens), medium (e.g., CAVE systems), and high (e.g., VR headsets) categories. Low technological immersion TV screens provide non-surround projection and no visual isolation from physical reality, medium technological immersion CAVE systems provide surround projection but limited visual isolation from physical reality, while high technological immersion VR headsets provide surround projection and complete visual isolation from physical reality (Li et al., 2023).

Psychological immersion, meaning immersion as a psychological phenomenon experienced by an individual, refers to "a state of deep mental involvement in which the individual may experience disassociation from the awareness of the physical world due to a shift in their attentional state" (Agrawal et al., 2020). In other words, technological immersion is an objective feature of the technology, whereas psychological immersion is a subjective experience of the user (Schubert et al., 2001). In the present study, we use the term "technological immersion" when referring to the property of the technology and the term "psychological immersion" when referring to immersion as a psychological outcome.

When experiencing virtual environments, a certain sense of being in the virtual environment emerges. This is apparent especially in the case of such media that involves a three-dimensional space for the user (Schubert et al., 2001). Such phenomenon is called presence (or telepresence, which some authors have used to describe "the degree to which an user feels present in the virtual rather than the physical environment"; cf. Rauschnabel et al., 2022). Presence generally refers to the "sense of being there" (Schubert et al., 2016). In this study, we refer with presence particularly to this sense of being in the virtual environment. Whereas immersion can be operationalized either from a technological or a psychological perspective, presence is a purely psychological phenomenon. Slater and Wilbur (1997) define presence as "a state of consciousness, the (psychological) sense of being in the virtual environment." Schubert et al. (2001) extend this by presenting that the experience of presence includes the subjective components of spatial-constructive, attention facets, and judgments of realness. Spatial-constructive component refers to the sense of being physically present in the virtual environment, attention facets component refers to the paid attention to real and virtual environment and related involvement, and judgment of realness component refers to the comparison between the virtual and the real world (Schubert et al., 2001).

Thus, whereas technological immersion is an objective quality of the technology, psychological immersion and presence are both subjective psychological outcomes. The use of these terms has been vague in the literature, and they are often used interchangeably (Nilsson et al., 2016). This is not surprising considering the partly overlapping character of psychological immersion and presence (Nilsson et al., 2016). Moreover, there is no consensus on the definition of immersion (Agrawal et al., 2020), and immersion has been categorized in numerous ways (Nilsson et al., 2016). Hence, to clarify the distinct character of psychological immersion and presence, in the context of the present study we refer with psychological immersion to the temporal dissociation, focus, and engagement related to the virtual experience (Agarwal & Karahanna, 2000), whereas with presence, we refer to the general sense of being in the virtual environment (Schubert et al., 2016; Slater & Wilbur, 1997).

It is often assumed that higher technological immersion leads to higher presence (Cummings & Bailenson, 2015) and psychological immersion (Nilsson et al., 2016), which subsequently enhance the effectiveness of the virtual experience (Cummings & Bailenson, 2015). In the context of virtual nature, this would mean that increased technological immersion would improve presence and psychological immersion, subsequently leading to better psychophysiological outcomes of virtual nature exposure (Litleskare et al., 2020). Indeed, virtual nature reviews have reported that technological immersion can influence the psychophysiological outcomes of virtual nature exposure (e.g., Bolouki et al., 2025; Li et al., 2023). Reviews have also implied on the important mediating role of presence in receiving positive outcomes from virtual nature exposure (e.g., Bolouki et al., 2025; Spano et al., 2023), however, extant virtual nature research has not provided conclusive evidence on the role of technological immersion behind presence (Bolouki et al., 2025).

Concerning psychophysiological outcomes, in a recent systematic review by Bolouki et al., (2025), which analyzed 78 research articles on the impact of virtual nature on psychological and physiological wellbeing outcomes published between 2010 and 2023, nine articles also examined the effect of technological immersion on these outcomes. Of those nine, eight found that technologies with high technological immersion (i.e., VR headsets) are more effective in providing psychophysiological benefits than technologies with low technological immersion (i.e., screens). However, the relationship does not always seem to be linear as the findings have been mixed. For example, a review by Li et al. (2023), including 28 studies on the effects of virtual nature of which 11 examined the impact of technological immersion on positive affect, found that technologies with medium technological immersion (e.g., CAVE systems) produced a large effect on positive affect improvement, whereas technologies with low technological immersion (e.g., TV screens) and high technological immersion (e.g., VR headsets) produced small effects. They discussed that technologies with high technological immersion could make users feel uncomfortable, particularly if they get cybersickness symptoms (Li et al., 2023). Following the technological immersion level categorization by Li et al. (2023), the authors investigated the psychological benefits (restoration, stress, affect, subjective vitality) of different delivery technologies in a related study (Kari et al., 2024), and found that technologies with medium technological immersion (e.g., room-scale) might be the most potential ones for providing psychological benefits with a small margin over technologies with high technological immersion (VR headset), whereas technologies with low technological immersion (TV screen) seemed the least potential.

A recent review by Wang et al. (2025) showed that so far, there are no reliable ways to link physiological measures with virtual environment related presence or immersion, as these measures are not specific to presence or immersion. For example, characteristics of the autonomic nervous system (sympathetic and parasympathetic activity) are not exclusive markers of immersion or presence; rather, they primarily reflect stress reactions and cognitive load (such as heart rate, heart rate variability, skin conductance, etc.). This can be illustrated by the studies that have used psychophysiological markers for comparing different virtual nature conditions. In the randomized controlled trial by Knaust et al. (2022), skin conductance level indicated stress reduction when participants viewed a nature video using either a VR-headset or a screen, compared to a control condition. Heart rate remained consistent across all conditions, whereas a self-reported single-item measure of relaxation favored the VR-headset condition over the others.

To summarize, there are several studies investigating how certain delivery technologies with varying technological immersion affect the psychophysiological outcomes of virtual nature exposure (cf. Bolouki et al., 2025; Browning et al., 2021). However, there is limited research and mixed results on how technological immersion affects presence in virtual nature. Bolouki et al. (2025) concluded in their systematic review that their findings did not provide conclusive evidence about which specific virtual nature delivery technologies are associated with a greater sense of presence. Further, there is also very limited research on how technological immersion affects psychological immersion in virtual nature.

Thus, considering the limited research and inconclusive evidence, more research is needed to reveal the capabilities of different delivery technologies to induce psychological immersion and presence during virtual nature exposure.

2.2. Virtual reality sickness

In virtual environments, users can experience motion sickness-like symptoms such as nausea or vertigo, which are usually resulting from sensory conflict induced by the mismatch between visual and vestibular inputs or the visual stimuli and technology itself (Chang et al., 2020). Such symptoms are typically referred to as VR sickness or cybersickness. VR sickness, being a negative embodied experience, can also increase physical discomfort (Kari & Kosa, 2023). These kinds of symptoms can have a significant negative effect on the perceived experience and even lead to use discontinuance (Ang & Quarles, 2023). VR sickness is a pertinent issue also in the context of virtual nature (Spano et al., 2023). It is also an important issue to solve as it can limit the potential positive effects of virtual nature exposure (Calogiuri et al., 2017; Hejtmánek et al., 2022). For example, in the study by Calogiuri et al. (2017) where virtual nature was delivered using VR headsets, cybersickness was negatively correlated with enjoyment, positive affect, and tranquility, and positively correlated with negative affect. Hejtmánek et al. (2022) found that cybersickness symptoms lessened the gained benefits on relaxation and emotional state during virtual nature experience. Thus, reducing VR sickness symptoms, for example by choosing the right delivery technology, is highly important. Studies have also shown that longer exposure times generally lead to more severe VR sickness symptoms (e.g., Chen & Weng, 2022), further emphasizing the need to choose a technology that allows continuous use. For a more comprehensive overview of VR sickness and related factors, we refer the interested reader to the works by Chang et al. (2020) and Ang and Quarles (2023).

Chang et al. (2020) classified the causes for VR sickness to three major factors: hardware, content, and human factors. In the present study, we focus specifically on the hardware factor. Previous studies have found that from different technologies, especially VR headsets are prone to cause VR sickness (e.g., Martirosov et al., 2022; Mittelstaedt et al., 2018; Weidner et al., 2017; Yildirim, 2020). For example, Mittelstaedt et al. (2018) found that VR headsets are more prone than large TV screens to induce cybersickness. Yildirim (2020) made a similar finding when comparing VR headsets with a desktop screen. Weidner et al. (2017) reported that VR headsets significantly increased cybersickness in comparison to stereoscopic 3D screens. Martirosov et al. (2022), comparing VR sickness symptoms between a VR headset, a CAVE system, and a PC screen, found that VR headset caused more VR sickness symptoms than the other two conditions. Along the same line, Frost et al. (2022) note the potential advantage of virtual nature rooms over VR headsets in terms of lesser VR sickness. Thus, the chances for VR sickness are likely smaller in virtual nature rooms and with TV screens than with VR headsets.

To be noted is that the technological fidelity of a given technology can play a role as well. For example, field of view, framerate, resolution, and other technical factors can influence the level of VR sickness (Saredakis et al., 2020), meaning that more advanced VR headsets, or TV screens and virtual nature rooms for that matter, probably induce lesser VR sickness. However, in the present study our focus is not on comparing different brands or products but different contemporary technologies.

2.3. The present study

The purpose of the present study was to increase the understanding on how the used delivery technology affects the psychological immersion, presence, and VR sickness symptoms in virtual nature. The specific focus was on comparing three different technologies with varying technological immersion (low, medium, high) for delivering virtual nature: 75″ TV, virtual nature room, and VR headset. To our best knowledge, this is the first study to compare these outcomes between a room-scale virtual nature solution, a VR headset, and a TV. Notably, room-scale virtual nature systems have been seldomly used in research so far (cf. Browning et al., 2021; Frost et al., 2022).

A key difference between using a VR headset and a virtual nature room is that whereas a virtual nature room typically only enables a 360-degree view on four-walls (excluding seeing whatever is above or below the user's viewpoint), a VR headset enables a full 360-degree view (including seeing whatever is above or below the user's viewpoint). Virtual nature room, on the other hand, does not require the users to wear a headset. Nonetheless, both technologies allow many view directions to the environment and enable the presentation of the virtual environment as a space, whereas a TV is limited to one pre-selected view direction of the environment. A more detailed description of these conditions is given in section 3.3. Reflecting to the categorization by Li et al. (2023), while not totally unambiguous, TV would be classified to have low technological immersion, virtual nature room (as it resembles a CAVE systems) would be classified to have medium technological immersion, and VR headset would be classified to have high technological immersion.

The used virtual nature material was a 360-degree forest video with matching soundscape. The same material was used for all the conditions. In the absence of best practice and considering the various exposure durations used in previous studies (cf. Browning et al., 2021), the length of the virtual nature exposure was set to 15 min to allow enough time for the participants to experience psychological immersion and presence.

Based on the research questions and the previous literature presented above, the following research hypotheses were formed:

Hypothesis 1 a (1-tailed): An experimental condition with virtual nature room is a more effective setting than the TV condition for inducing overall psychological immersion and its different forms (focused immersion, temporal dissociation) as well as overall presence and its different forms (general presence, spatial presence, involvement, experienced realism).

Hypothesis 1 b (1-tailed): An experimental condition with VR headset is a more effective setting than the TV condition for inducing overall psychological immersion and its different forms (focused immersion, temporal dissociation) as well as overall presence and its different forms (general presence, spatial presence, involvement, experienced realism).

Hypothesis 2 (2-tailed): There is a difference between virtual nature room condition and VR headset condition in the effectiveness for inducing overall psychological immersion and its different forms (focused immersion, temporal dissociation) as well as overall presence and its different forms (general presence, spatial presence, involvement, experienced realism).

Hypothesis 3 a (1-tailed): An experimental condition with VR headset is more prone than an experimental condition with TV to induce overall VR sickness and its different forms (oculomotor, disorientation).

Hypothesis 3 b (1-tailed): An experimental condition with VR headset is more prone than an experimental condition with virtual nature room to induce overall VR sickness and its different forms (oculomotor, disorientation).

3. Methodology

3.1. Study design and procedures[1]

The study applies a three-condition randomized trial with a crossover design (Jones & Kenward, 2015), in which there were one measurement of each psychological variable within each visit. Study participants were randomized to six different condition order groups (123,132,213,231,312,321: 1. TV, 2. VR headset, 3. virtual nature room). Each participant visited three separate experimental sessions with different experimental condition (i.e., each study participant visited once in each of the three different conditions). The participants visited each condition alone (i.e., there were no other participants in the same condition simultaneously).

The experiment was conducted between March and early-June 2023 (springtime). All the three conditions took place in the same physical location, a virtual nature laboratory located in Helsinki, Finland. By

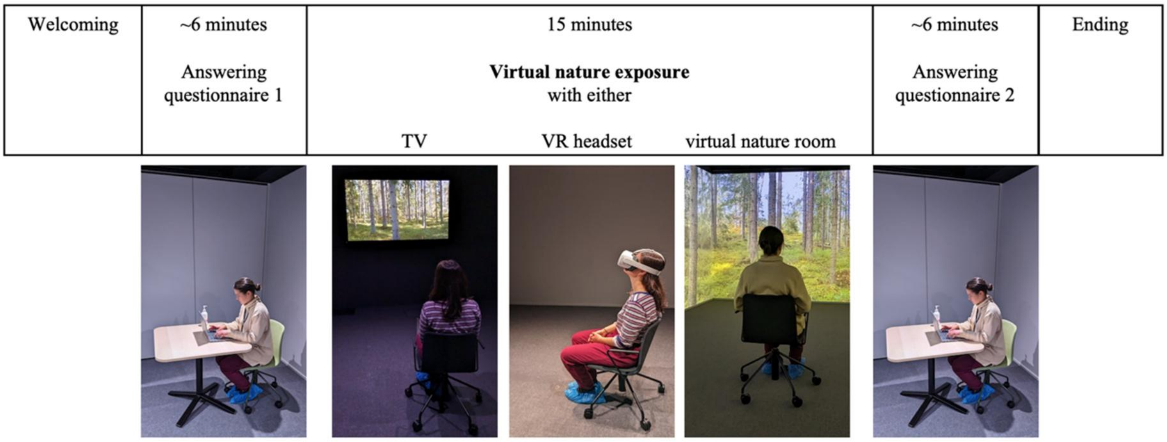

Figure 1. The experimental setting. For higher resolution images, see Supplementary C.1, C.2, C.3, and C.4.

default, the participants were proposed a seven-day interval between each experimental session, but they could choose the dates of the sessions to suit their schedule as long as there was a minimum of seven days between the sessions. All experimental sessions took place between 8:00am and 16:00pm.

The experimental sessions followed the course shown in Figure 1. One week before the first experimental session, all participants received an invitation link to their emails to answer a background questionnaire, which had to be answered before the first visit. The background questionnaire included demographic questions, questions about technology use, outdoor activities, nature relatedness, and similar. At the beginning of each experimental session, the participant was welcomed and requested to disinfect or wash their hands. They then wore a Polar H10 heart rate sensor around their chest (to record ECG measures for a purpose of another study) and were guided to sit by a desk to answer the before-exposure questionnaire with a computer. After completing the questionnaire, the participant was instructed into the experimental condition they had that day. They did not know beforehand which condition they had coming in each session, with the obvious exception of the last session when there was only one condition left. Then the participant underwent a 15-minute virtual nature exposure in either TV, VR headset, or virtual nature room condition. After the virtual nature exposure, the participant was again guided to sit by a desk to answer the after-exposure questionnaire with a computer. The after-exposure questionnaire included the questions measuring psychological immersion, presence, and VR sickness, which were investigated in the present study. This questionnaire and the before-exposure questionnaire also included some other questions, which were collected for a purpose of another study (Kari et al., 2024) The questionnaires were administered with the Webropol survey tool (Webropol Oy, 2022). Each experimental session lasted for approximately 35–40 min in total.

The study was conducted following the principles of the Declaration of Helsinki. The ethical review statement was given by the Ethics Committee for Human Sciences at the University of Turku. Before the study experiment, the participants were presented with comprehensive information regarding the study in general, the experimental sessions, and their rights as participants. The goals of the study were presented on a general level (i.e., to create new knowledge and insights about the effects of virtual nature). The structure of the experimental sessions was presented in a more detailed manner, including explaining the welcoming procedure, mentioning the different delivery technologies, the exposure time, and responding to surveys. Presenting this information is an ethical requirement. However, we aimed to present all the information in a manner that would not influence the results. All the participants provided a written informed consent.

3.2. Participants

To recruit the participants, different recruitment methods were used. Ads about the study were shared on physical and digital bulletin boards as well as on different mailing lists, flyers were handed out to people, and few recruitment days were organized in a campus area hosting an university and various other organizations. Participation was completely voluntary, and no power dynamics, persuasion, or

Table 1. Sociodemographic characteristics of the participants.

Characteristic	*n*	%
Gender		
Woman	42	67.7
Man	20	32.3
Age group		
22–29 Years	12	19.4
30–39	20	32.2
40–49	15	24.2
50–63	15	24.2
Ethnic identity		
White	62	100.0
Highest educational degree		
University	52	83.9
University of applied sciences	4	6.5
Upper secondary school, gymnasium or equivalent	6	9.7
Living environment		
City center	9	14.5
City suburb	47	75.8
Municipality area or countryside	6	9.7
Closest green area for recreation from home		
<200m	21	33.9
>200–500 m	21	33.9
>500m – 1 km	15	24.2
>1km	7	8.0

pressure was used in the recruitment. None of the participants were students of the authors. The participants did not receive any compensation for participation. The participant recruitment procedure was approved by the Ethics Committee.

In total, 63 participants joined the study, but after one drop-out (due to clash of schedules), the final sample consisted of 62 participants. Of them, 42 identified as woman and 20 as man (gender was asked with response options: Woman, Man, Transgender, Non-binary/non-conforming, and Prefer not to respond, but all respondents identified themselves as either woman or man). Their age varied between 22 and 63 years with the mean age of 40.42 years (SD = 11.01). In terms of technology use, 66.1% had tried a VR headset before, but only one participant was using them regularly. 40.3% had tried a room-scale virtual solution (without a VR headset) before, but only two participants had more experience beyond trying. The central demographics are presented in Table 1. The whole descriptive statistics of the sample are presented in Supplementary A: Sample descriptive statistics.

The exclusion criteria for participation were mainly related to the ECG measures, which were recorded for a purpose of another study. These included confirmed diagnoses of different cardiovascular diseases, asthma requiring maintenance treatment, sleep apnea, epilepsy, clinical depression, and alcoholism. Further exclusion criteria were ongoing steroid medication, medication that affects heart rate, as well as smoking and drug use during the past month. The participants were instructed to avoid excessive use of caffeine, alcohol, and intense physical exertion on the days of the experimental sessions.

3.3. The conditions and the virtual nature material

3.3.1. The conditions

In the TV condition (low technological immersion), the virtual nature was delivered via a 75″ TV screen and a 4-channel surround sound system. From the TV screen, the participants saw around one fifth of the whole 360-degree view of the virtual nature video. TV condition took place in a 16 m^2 square-shaped room, and all the lights in the room were off during the exposure. The participants sat on an office chair 2.6 meters away from the TV. This viewing distance was based on the recommendation for TV viewing distance by THX and Home Cinema Guide (Home Cinema Guide, 2022). The participants were instructed to watch the TV for the whole 15-minute exposure and to not move around with the chair or rotate it. Decibel measurements showed that the sound average was 43.0 dB(A) during the TV condition. During the exposure, the researcher sat quietly in a corner behind the participant. For an overview of the TV condition, see Figure 1 or Supplementary C.1.

In the VR headset condition (high technological immersion), the virtual nature was delivered via Meta Quest 2 headset, which has 6-DoF, 1832 × 1920 resolution per eye, and a positional sound system inside the headset (Meta, 2022). The VR headset enabled a full 360-degree view of the virtual nature. The sounds were played directly from the headset, instead of the room's surround sound system. The condition took place in the same room and the participants sat on the same revolving office chair as in the TV condition. The participants were instructed to avoid moving the chair from its place, but they could revolve it and tilt their head around to see the whole view. If the participant had eyeglasses or contact lenses, they could decide themselves whether or not to use those with the headset. For those wearing eyeglasses, a spacer was installed to the headset to increase comfort. Hygiene pads were used and replaced after every use, and in addition, the headset was disinfected after every use. Decibel measurement was not possible as the sounds were played directly from the headset, but the researcher adjusted the volume to match other conditions as closely as possible. During the exposure, the researcher sat quietly in a corner of the room. For an overview of the VR headset condition, see Figure 1 and Supplementary C.2.

In the virtual nature room condition (medium technological immersion), the virtual nature was delivered in a 30 m^2 rectangle-shaped room with six video projectors and an 11-channel ambisonic sound system, which enabled a room-scale 360-degree view projected on the four walls of the room. All the lights in the room were off during the exposure. The participants sat on a revolving office chair in the middle of the room. They were instructed to not move the chair from its place, but they could revolve it to see the whole view. Decibel measurements showed that the sound average was 47.0 dB(A) during the virtual nature room condition. During the exposure, the researcher sat quietly behind the door, so that the participant could experience the virtual nature room by themselves. For an overview of the virtual nature room condition, see Figure 1 and Supplementary C.3. The room temperature for all the conditions was set to 22° C.

3.3.2. The virtual nature material

The same 15-minute audio-visual material, including a static video with a matching soundscape, was used across all the three conditions. The video was static, that is, there was no camera movement, and the viewer perspective did not move in the virtual nature. However, there was some object movement in the video such as tree branches slightly swaying in the wind, which can make the virtual nature feel more "life-like" (Litleskare et al., 2020). Using the same virtual nature material enables a genuine comparison of different technologies. Further, we decided to keep the experience simple as the movement in or interaction with the virtual environment would be very different when using a TV, VR-headset or a room-scale solution. This kind of cinematic virtual reality environment (cf. Dooley, 2021; MacQuarrie & Steed, 2017) utilizing 3-DoF instead of 6-DoF provided the participant a freedom and choice of where to look (a choice that also exist with TV but to a much more limited extent; Dooley, 2021) but restricted them from moving or interacting with the elements of the virtual environment. Thus, the confounding influence of the participants' actions (i.e., movement and interaction) to the results was diminished. Subsequently, using this kind of cinematic virtual environment enabled comparing the propensities of the selected delivery technologies and measure the investigated outcomes better. Previous studies on the effects of actual and virtual nature have often used similar conditions (viewing static nature).

The material was recorded in the fall of 2022 during a partly cloudy/sunny day in a semi-open coniferous forest typical for the region (Figure 2; Supplementary C.5). The exact location of recording, situated in Sipoonkorpi National Park, was chosen based on our expert evaluation and on prior studies on preferred and restorative forest environments (e.g., Simkin et al., 2020, 2021). The selected location exhibited relatively low visual complexity, which facilitated clear visibility throughout the forest stand. The understory layer was sparse, resulting in minimal visual obstruction and limited terrain variation. The forest structure was dominated by mature spruce trunks, interspersed with a small proportion of deciduous trees. As the used material was recorded only 20 km away from the study laboratory, it

Figure 2. The forest landscape used in the experiment.

represented a familiar and nonthreatening landscape and forest type to the participants. Using an unfamiliar environment or one with a lot of action could have skewed the results.

The recording was made with Insta360 Pro 2 8K 360-degree camera (Arashi Vision Inc, 2024a) and an ambisonic sound recording system (RØDE, 2024; Zoom, 2024). Both the video and the sound were recorded simultaneously. Post-production was done by using Insta360Stitcher (Arashi Vision Inc, 2024b) and Adobe Premiere Pro 2023 (Adobe, 2023) software for the video and Reaper software (Cockos Inc, 2024) for the sound. No edits were applied to the material except for airplane noise being removed from the soundtrack. Before the experiment began, the authors and few independent evaluators tested the material with the technologies used in the study. The material was considered very suitable for the study.

3.4. Outcome measures and statistical analysis

3.4.1. Outcome measures and covariates

Different psychological scales were used to measure the participants' self-reported psychological immersion, presence, and VR sickness. The participants answered the scales directly after experiencing each experimental condition.

To measure overall psychological immersion, an eight-item measure combining three items from the Temporal dissociation (TD) scale and five items from the Focused immersion (FI) scale was used (adapted from Agarwal & Karahanna, 2000). TD refers to "the inability to register the passage of time while engaged in interaction," while FI refers to "the experience of total engagement where other attentional demands are, in essence, ignored" (Agarwal & Karahanna, 2000, p. 673). Similar operationalization of immersion (TD+FI) has been used, for example, in the seminal paper by Lowry et al. (2012). In addition to investigating the overall psychological immersion outcome, the TD and FI were also analyzed as separate outcomes.

To measure overall presence, the 14-item igroup presence questionnaire (IPQ) (modified from Schubert et al., 2001, 2016) was used. It contains subscales for general presence (G), spatial presence (SP), involvement (INV), and experienced realism (REAL). G assesses the "general sense of being there"; SP assesses the "sense of being physically present in the virtual environment"; INV assesses "the attention devoted to the virtual environment and the involvement experienced"; and REAL assesses the "subjective experience of realism in the virtual environment" (Schubert et al., 2016). One of the strengths of the IPQ is that these subscales allow a more nuanced analysis of presence. Hence, in addition to investigating the overall presence outcome, these subscales were also analyzed as separate outcomes. IPQ has been widely used to measure presence (cf., Schwind et al., 2019) and in the paper by Schwind et al. (2019) on using presence questionnaires in virtual reality, they recommend using IPQ to measure presence in virtual environments over other potential measures, as it "provides the highest reliability within a reasonable timeframe" (Schwind et al., 2019, p. 10). In present study, the original IPQ scale was modified to be simpler to respond, more precisely, the statements were modified so that they could be measured with the anchors fully disagree–fully agree. In addition, the term *computer generated world* in the original scale was replaced by the term *virtual nature*.

To measure VR sickness, the nine-item Virtual reality sickness questionnaire (VRSQ) (Kim et al., 2018) was used. The VRSQ has two subscales: oculomotor and disorientation. Oculomotor subscale consists of general discomfort, fatigue, eyestrain, and difficulty focusing, whereas the disorientation subscale consists of headache, fullness of head, blurred vision, dizziness, and vertigo (Kim et al., 2018). As these subscales are of different type, in addition to investigating the overall VR sickness, these subscales were also analyzed as separate outcomes. The VRSQ has been widely used for measuring sickness symptoms in virtual environments (e.g., Koltai et al., 2019; Qu et al., 2022; Widyanti & Hafizhah, 2022).

The immersion (TD+FI) and IPQ were all measured by a 7-point Likert scale with the response options ranging from 1 (fully disagree) to 7 (fully agree). The VRSQ was measured by a 4-point scale with the response options ranging from 0 (not at all) to 3 (very much), and a score was calculated for overall VRSQ as well as for oculomotor and disorientation subscales. The items of all the psychological measures and the formula for calculating VRSQ are presented in Supplementary E: Measures and items.

Age and gender are typical covariates in psychological research as well as the most commonly controlled sociodemographic features in virtual nature research (Browning et al., 2021). The review by Weech et al. (2019) showed that gender might influence both cybersickness and presence in virtual environments, though the direction is not clear due to mixed findings. Similar findings have been made in terms of age (e.g., Dilanchian et al., 2021; Lorenz et al., 2023), however, also with age the findings have been mixed. Hence, we have added age and gender as covariates.

3.4.2. Statistical analysis

The study applies a three-condition randomized trial with a crossover design, in which there were one measurement of each psychological variable within each visit. This approach is generic and widely adopted in psychological and clinical research, providing scientifically rigorous base for analysis. It can also be applied in other crossover experiments regardless of the topic. Study participants were randomized to six different condition order groups (123,132,213,231,312,321: 1. TV, 2. VR headset, 3. virtual nature room). Each study participant visited once in each condition. The study design is a three-condition, three-visit, six-condition order crossover study with a model structure:

Response variable = Intercept + Visit(F) + Condition(F) + Condition order(F) + Gender(F) + Covariate(F) + Visit day(R).

In the formula, F stands for fixed effect, and R for repeated random effect. Gender and age (continuous variable) were included as covariates. Visit day is a continuous variable and it is used to model the covariance structure due to uneven time intervals between visits, with each study participant (identified by Person ID) as the individual unit/subject. Condition order -term estimates the carryover-effect and in the case of $p < 0.05$ only the 1st visit data will be analyzed.

A general linear mixed model was fitted using normal distribution assumption (identity link) (Stroup, 2013). The model fit was checked from the shape of Pearson residuals and from the observed vs. predicted plots.

For Presence–involvement, VR sickness disorientation score, VR sickness oculomotor score, and VR sickness total score a logarithmic transformation was applied. Additionally, with VR sickness disorientation score, VR sickness oculomotor score, and VR sickness total score all zero values were replaced with 0.5 before taking logarithm. After transformations, the residual distributions of all response variables were adequate. See Supplementary B: Statistical analyses for more details.

The effect of statistical outliers (|Pearson residual|>2.5) were checked by removing these values from the data. The interpretation of the results did not change except with IPQ-REAL variable for which an additional analysis was conducted. For rest of the variables, the full data was used (Supplementary D.1; D.2; D.9). In the model without age and gender, the interpretation of the results remained intact (Supplementary D.1; D.3; D.9) and the results of the original model with covariates were followed.

A Kenward-Roger approximation was used to analyze degrees of freedom. Statistical tests were based on predefined contrast comparisons according to study hypothesis, and simulation-based multiplicity-adjustment – to account for type 1 error – were used when applicable (Westfall, 1997).

Predefined statistical contrast comparisons according to study hypothesis:

For inducing overall psychological immersion and its different forms (focused immersion, temporal dissociation) as well as overall presence and its different forms (general presence, spatial presence, involvement, experienced realism):

a. H1a virtual nature room > TV: |difference estimate| > 0 (1-sided *t*-test)

b. H1b VR headset > TV: |difference estimate| > 0 (1-sided t-test)
c. H2 virtual nature room ≠ VR headset: difference estimate ≠ 0 (2-sided t-test)

For inducing overall VR sickness and its different forms (oculomotor, disorientation):

a. H3a VR headset > TV: |difference estimate| > 0 (1-sided t-test)
b. H3b VR headset > virtual nature room: |difference estimate| > 0 (1-sided t-test)

All results presented are adjusted for gender and age. The modeling was performed by the GLIMMIX procedure of the SAS/STAT software (version 9.4, SAS Institute, 2020).

Power and sample size calculations were done for Restoration (ROS) variable, which was collected in the same experiment but reported in another study (Kari et al., 2024), and the parameters involved in the present study are subordinated to that. According to the power analysis, the required number of participants was at least $N = 60$.

A detailed description of statistical analyses, handling of covariates, effect size calculations, and power and sample size calculations are given in Supplementary B: Statistical analyses.

4. Results

4.1. Covariates and carryover effect

Statistically significant effects of gender and age in the models were found: age having a negative slope for TD (−0.0333, 95% CI −0.056 to −0.011), which means that 10-unit difference between two study participants in age affected 0.333-unit decrease in response change variable TD; and in gender women having a 0.637 higher estimate than men in TD (0.637, 95% CI 0.113–1.161) (Supplementary D.4, D.11). In other words, older person got a smaller TD value compared to younger person, and women got a higher TD value compared to men. No other statistically significant effects of gender or age in the models were found including carryover effects.

4.2. Differences between the conditions

4.2.1. Model estimated mean values of response variables

For model estimated mean values of response variables, see Supplementary D.1 and D.10. These are also visible in Figures 3 and 4.

4.2.2. Psychological immersion and presence

In terms of the main effect of condition (Table 2; Figure 3; Supplementary D.1), the participants' overall immersion, focused immersion (FI), and temporal dissociation (TD) were higher in the VR headset condition than in the TV condition (Immersion: −1.299, 90% CI −1.694 to −0.904, Cohen's d −0.573; FI: −1.629, 90% CI −2.041 to −1.218, Cohen's d −0.700; TD: −0.743, 90% CI −1.235 to −0.252, Cohen's d −0.271).

Similarly, overall immersion, focused immersion, and temporal dissociation were higher in the virtual nature room condition than in the TV condition (Immersion: −0.813, 90% CI −1.207 to −0.419, Cohen's d −0.364; FI: −0.742, 90% CI −1.152 to −0.332, Cohen's d −0.323; TD: −0.935, 90% CI −1.426 to −0.445, Cohen's d −0.346).

When comparing the VR headset and virtual nature room conditions, overall immersion and focused immersion were higher in the VR headset condition (Immersion: 0.486, 95% CI 0.030–0.942, Cohen's d 0.219; FI: 0.887, 95% CI 0.418–1.356, Cohen's d 0.391). With temporal dissociation, no statistically significant difference was observed between VR headset and virtual nature room conditions. In all of the above, the effect sizes measured by Cohen's d were small to medium (Cohen, 1988).

The participants' overall presence (IPQ), general presence (IPQ_G), involvement (IPQ_INV), experienced realism (IPQ_REAL), and spatial presence (IPQ_SP) were higher in the VR headset condition than in the TV condition (IPQ: −1.729, 90% CI −2.074 to −1.383, Cohen's d −0.875; IPQ_G: −2.361,

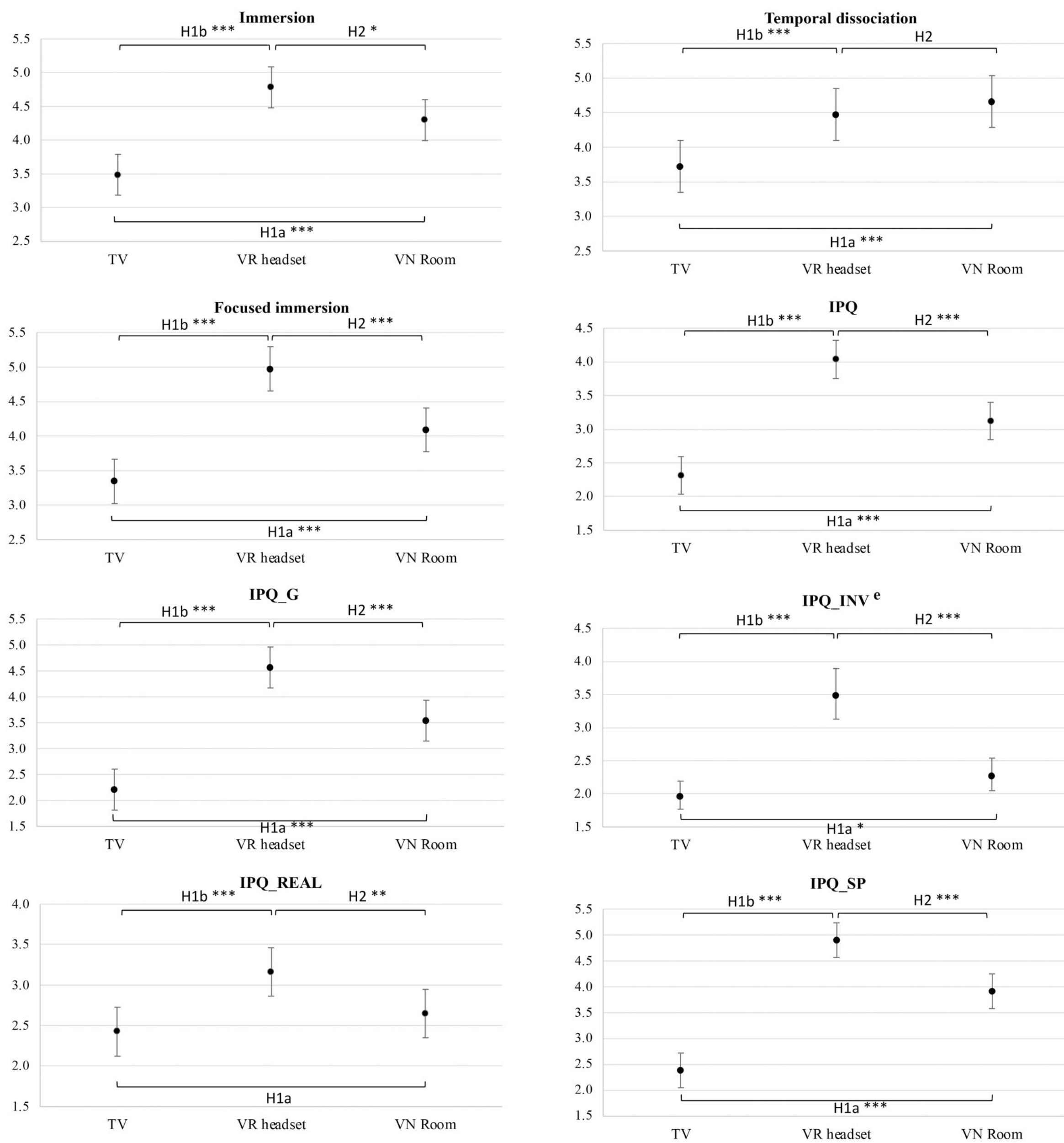

Figure 3. Differences between the conditions. Dots and error bars describe the response variable mean values and their 95% confidence intervals. The connection lines describe statistically significant differences between the conditions (condition A minus condition B) (hypotheses H1a, H1b, H2). *Note:* $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$. Immersion: overall immersion; FI: focused immersion; TD: temporal dissociation; IPQ: overall presence; IPQ_G: general presence; IPQ_INV: involvement; IPQ_REAL: experienced realism; IPQ_SP: spatial presence. VN room: virtual nature room. [e] back-transformed from log-scale estimates (Supplementary D.1).

90% CI −2.867 to −1.855, Cohen's d −0.823; IPQ_INV[2]: *0.564, 90% CI *0.488–0.651, Cohen's d −0.701; IPQ_REAL: −0.737, 90% CI −1.090 to −0.384, Cohen's d −0.367; IPQ_SP: −2.515, 90% CI −2.936 to −2.093, Cohen's d −1.049).

Similarly, except for the experienced realism where there was no statistically significant difference, the presence outcomes were higher in the virtual nature room condition than in the TV condition (IPQ: −0.813, 90% CI −1.158 to −0.469, Cohen's d −0.417; IPQ_G: −1.331, 90% CI −1.836 to −0.827, Cohen's d −0.470; IPQ_INV[2]: *0.864, 90% CI *0.749–0.997, Cohen's d −0.181; IPQ_SP: −1.529, 90% CI −1.949 to −1.109, Cohen's d −0.646). In the above presence comparisons, the effect sizes ranged from small to large (Cohen, 1988).

Table 2. Differences between the conditions (condition a minus condition B) (hypotheses H1a, H1b, H2).

Measure (H)	Estimate	*CI*	*t*	*df*	Adjusted *p*	Cohen's *d*
Immersion						
1 vs.2 (H1b)	−1.299	(−1.694) to −0.904	−6.745	138.5	**<0.0001**	−0.573
1 vs. 3 (H1a)	−0.813	(−1.207) to −0.419	−4.234	135.5	**<0.0001**	−0.364
2 vs. 3 (H2)	0.486	0.030 to 0.942	2.535	133.5	**0.012**	0.219
FI						
1 vs.2 (H1b)	−1.629	(−2.041) to −1.218	−8.219	137.8	**<0.0001**	−0.700
1 vs. 3 (H1a)	−0.742	(−1.152) to −0.332	−3.755	134.9	**0.0001**	−0.323
2 vs. 3 (H2)	0.887	0.418 to 1.356	4.503	132.5	**<0.0001**	0.391
TD						
1 vs.2 (H1b)	−0.743	(−1.235) to −0.252	−3.156	135.9	**0.001**	−0.271
1 vs. 3 (H1a)	−0.935	(−1.426) to −0.445	−3.984	132.8	**0.0002**	−0.346
2 vs. 3 (H2)	−0.192	−0.743 to 0.358	−0.821	130.6	0.413	
IPQ						
1 vs.2 (H1b)	−1.729	(−2.074) to −1.383	−10.310	138.8	**<0.0001**	−0.875
1 vs. 3 (H1a)	−0.813	(−1.158) to −0.469	−4.869	136.2	**<0.0001**	−0.417
2 vs. 3 (H2)	0.916	0.525 to 1.306	5.504	133.4	**<0.0001**	0.476
IPQ_G						
1 vs.2 (H1b)	−2.361	(−2.867) to −1.855	−9.650	137.6	**<0.0001**	−0.823
1 vs. 3 (H1a)	−1.331	(−1.836) to −0.827	−5.459	134.8	**<0.0001**	−0.470
2 vs. 3 (H2)	1.029	0.461 to 1.598	4.236	132.3	**<0.0001**	0.368
IPQ_INV						
1 vs.2 (H1b)	* 0.564	* (0.488) to 0.651	−8.258	138.7	**<0.0001**	−0.701
1 vs. 3 (H1a)	* 0.864	* (0.749) to 0.997	−2.107	135.7	**0.018**	−0.181
2 vs. 3 (H2)	* 1.533	* 1.301 to 1.807	6.185	133.8	**<0.0001**	0.535
IPQ_REAL						
1 vs.2 (H1b)	−0.737	(−1.090) to −0.384	−4.318	138.5	**<0.0001**	−0.367
1 vs. 3 (H1a)	−0.222	(−0.573) to 0.129	−1.307	136.1	0.097	
2 vs. 3 (H2)	0.515	0.116 to 0.914	3.052	132.7	**0.003**	0.265
IPQ_SP						
1 vs.2 (H1b)	−2.515	(−2.936) to −2.093	−12.345	138.4	**<0.0001**	−1.049
1 vs. 3 (H1a)	−1.529	(−1.949) to −1.109	−7.532	135.8	**<0.0001**	−0.646
2 vs. 3 (H2)	0.986	0.505 to 1.467	4.878	133.1	**<0.0001**	0.423

Note: Immersion: Overall immersion; FI: Focused immersion; TD: Temporal dissociation; IPQ: Overall presence; IPQ_G: General presence; IPQ_INV: Involvement; IPQ_REAL: Experienced realism; IPQ_SP: Spatial presence. Condition: 1 – TV, 2 – VR headset, 3 – virtual nature room. Cohen's *d* for observed effect were calculated when $p < 0.05$. Strictly, due to 1-sided hypotheses (H1a and H1b), the upper or lower confidence limit does not exist (within parenthesis) and the value in the CI column represents 90% CI; H2 is a 2-sided hypothesis and the value in the CI column represents 95% CI. *Data analysis were made in log-scale and these values are back-transformed to data scale describing the ratio of two mean values. If number 1 is included within confidence interval, the difference between mean values is not statistically significant at *p*-value 0.05 level. The significance of bold values is $p < 0.05$.

When comparing the VR headset and virtual nature room conditions, all the presence outcomes were higher in the VR headset condition (IPQ: 0.916, 95% CI 0.525–1.306, Cohen's *d* 0.476; IPQ_G: 1.029, 95% CI 0.461–1.598, Cohen's *d* 0.368; IPQ_INV[2]: *1.533, 95% CI *1.301–1.807, Cohen's *d* 0.535; IPQ_REAL: 0.515, 95% CI 0.116–0.914, Cohen's *d* 0.265; IPQ_SP: 0.986, 95% CI 0.505–1.467, Cohen's *d* 0.423). Here, the effect sizes were small to medium (Cohen, 1988).

4.2.3. VR sickness

In terms of the main effect of condition (Table 3; Figure 4; Supplementary D.1), the participants' disorientation (VRSQ_D) was higher in the VR headset condition than in the TV condition (VRSQ_D[3]: *0.206, 90% CI *0.132–0.322, Cohen's *d* −0.576). However, the oculomotor VR sickness (VRSQ_O) was higher in the TV condition than in VR headset condition (VRSQ_O[3]: *2.033, 90% CI *1.269–3.257, Cohen's *d* 0.249). The effect sizes measured by Cohen's *d* were small to medium (Cohen, 1988). Subsequently, there was no statistically significant difference in the overall VR sickness (VRSQ) between the VR headset and the TV conditions.

When comparing the VR headset and virtual nature room conditions, the participants' overall VR sickness (VRSQ) and disorientation (VRSQ_D) were higher in the VR headset condition than in the virtual nature room condition (VRSQ[3]: *2.017, 90% CI *1.379–2.951, Cohen's *d* 0.313; VRSQ_D[3]: *7.177, 90% CI *4.593–11.214, Cohen's *d* 0.730). The effect sizes were small to medium (Cohen, 1988). There was no statistically significant difference in the oculomotor VR sickness (VRSQ_O) between the VR headset and virtual nature room conditions.

For the model estimated differences in the psychological measures between the conditions, see Supplementary D.1. For covariate estimates, fixed effect parameter estimates, and random effect

Table 3. Differences between the conditions (condition a minus condition B) (hypotheses H3a, H3b).

Measure (H)	Estimate	*CI*	*t*	*df*	Adjusted *p*	Cohen's *d*
VRSQ						
1 vs. 2 (H3a)	*1.148	*(0.782) to 1.684	0.697	136.3	0.244	
2 vs. 3 (H3b)	*2.017	*1.379 to (2.951)	3.583	130.7	**0.0005**	0.313
VRSQ_O						
1 vs. 2 (H3a)	*2.033	*(1.269) to 3.257	2.901	136.3	**0.004**	0.249
2 vs. 3 (H3b)	*1.284	*0.804 to (2.050)	1.028	130.9	0.153	
VRSQ_D						
1 vs. 2 (H3a)	*0.206	*(0.132) to 0.322	−6.754	137.4	**<0.0001**	−0.576
2 vs. 3 (H3b)	*7.177	*4.593 to (11.214)	8.429	133.2	**<0.0001**	0.730

Note: VRSQ: VR sickness; VRSQ_O: VR sickness oculomotor; VRSQ_D: VR sickness disorientation. Condition: 1 – TV, 2 – VR headset, 3 – virtual nature room. Cohen's *d* for observed effect were calculated when $p < 0.05$. Strictly, due to 1-sided hypotheses (H3a and H3b), the upper or lower confidence limit does not exist (within parenthesis) and the value in the CI column represents 90% CI. *Data analysis were made in log-scale and these values are back-transformed to data scale describing the ratio of two mean values. If number 1.0 is included within confidence interval, the difference between mean values is not statistically significant at *p*-value 0.05 level. The significance of bold values is $p < 0.05$.

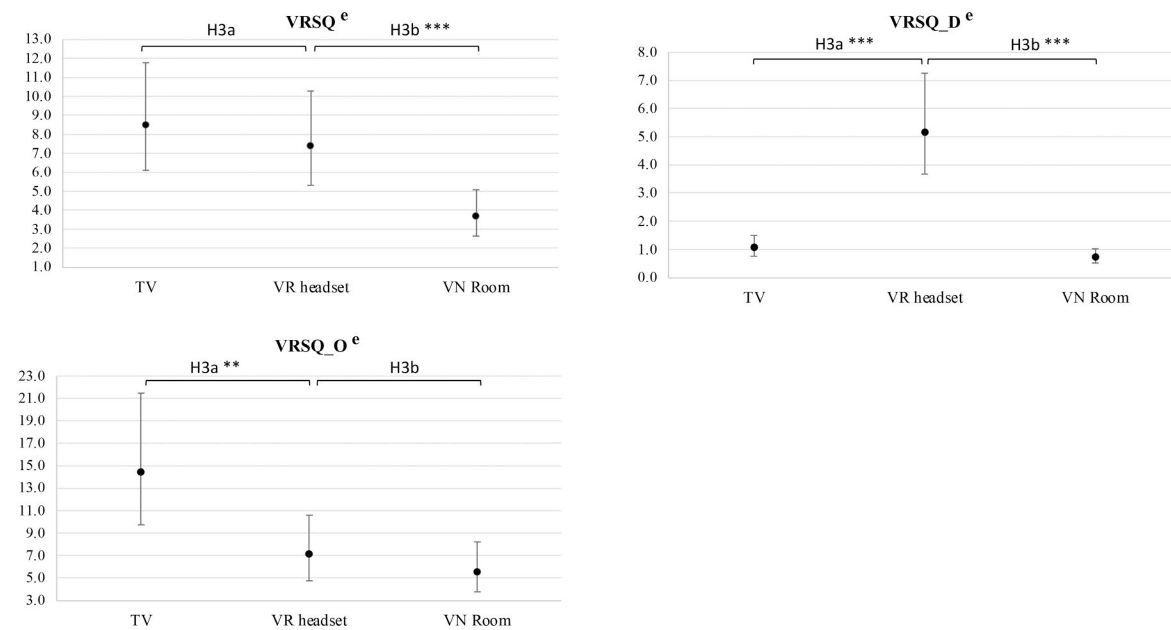

Figure 4. Differences between the conditions. Dots and error bars describe the response variable mean values and their 95% confidence intervals. The connection lines describe statistically significant differences between the conditions (condition A minus condition B) (hypotheses H3a, H3b). *Note:* ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. VRSQ: VR sickness; VRSQ_O: VR sickness oculomotor; VRSQ_D: VR sickness disorientation; VN room: virtual nature room. [e]back-transformed from log-scale estimates (Supplementary D.1).

parameter estimates, see Supplementary D.4. For model residual check and details, see Supplementary D.2, D.5, and D.9. For models without covariates and details, see Supplementary D.3, D.6, and D.9. For the descriptive statistics as well as for means and standard deviations of all the measures, see Supplementary D.7, and for the correlations, see Supplementary D.8.

5. Discussion

The present study provides a twofold contribution. First, our study increases the current understanding on how different delivery technologies with varying technological immersion can induce psychological immersion and presence as well as cause VR sickness symptoms in virtual nature setting. Second, our findings also extend to increasing the understanding on how such immersive technologies influence these outcomes in general. To our best knowledge, this is the first study to compare these outcomes between a room-scale virtual solution, a VR headset, and a TV in virtual nature context. Further, we make a distinction between technological and psychological immersion as well as clarify the distinct character of psychological immersion and presence. The use of these terms has been vague in the literature (Nilsson et al., 2016), thus we provide an exemplar on how to use these terms in research.

As hypothesized, both virtual nature room and VR headset were found to be more effective than TV in inducing psychological immersion and presence. Regarding H1a, overall immersion, focused immersion, and temporal dissociation, as well as overall presence, general presence, involvement, and spatial presence were higher in the virtual nature room condition than in the TV condition. The only outcome where there was no statistically significant difference between the virtual nature room and TV was experienced realism (a subscale of presence) (Table 2; Figure 3).

Regarding H1b, overall immersion, focused immersion, and temporal dissociation, as well as overall presence, general presence, involvement, experienced realism, and spatial presence were higher in the VR headset condition than in the TV condition (Table 2; Figure 3). This finding is in line with Liszio et al. (2018), who also found VR headset to be more effective than a screen in inducing psychological immersion and presence during virtual nature exposure.

H2 was also supported. In particular, we found that VR headset is more effective than virtual nature room in inducing psychological immersion and presence. Overall immersion and focused immersion were higher in the VR headset condition, whereas with temporal dissociation, no statistically significant difference was observed. Moreover, all the presence outcomes were higher in the VR headset condition than in the virtual nature room condition (Table 2; Figure 3).

Thus, it seems that technological immersion has a major role in producing psychological immersion and presence in virtual nature. The technology with highest technological immersion (VR headset) was clearly the most effective in inducing these outcomes – not just on overall level but also on subscale level. The difference was just as clear between the technology with medium technological immersion (virtual nature room) and the technology with low technological immersion (TV). Hence, our study suggests that the higher the technological immersion is, the higher the psychological immersion and presence outcomes are. This is in line with what Cummings and Bailenson (2015) and Nilsson et al. (2016) suggested, that is, higher technological immersion leads to higher presence and psychological immersion. Our study shows that this is also the case in virtual nature context.

Reflecting these findings from the perspective of technological immersion, we next discuss what could be the most important aspect affecting this. In their definition of technological immersion, Slater and Wilbur (1997, p. 3) highlighted the following four aspects: (1) Inclusive – “the extent to which physical reality is shut out”; (2) Extensive – “the range of sensory modalities accommodated”; (3) Surrounding – “the extent to which this virtual reality is panoramic rather than limited to a narrow field”; and (4) Vivid – “the resolution, fidelity, and variety of energy simulated within a particular modality.” Considering the Inclusive aspect of the investigated technologies, VR headset is obviously the best in shutting out physical reality as it provides a complete visual isolation from physical reality in comparison to a partial visual isolation of virtual nature room and no visual isolation of TV. In terms of the Surrounding aspect, both VR headset and virtual nature room provide a surround projection, though VR headset includes the sky and the ground, while virtual nature room does not. TV, on the other hand, is limited to a non-surround projection. In terms of the Extensive aspect, there was no difference between the investigated technologies in our study as all utilized visual and auditory modalities. Regarding the Vivid aspect, the used source content (video + sound) was the same across conditions. Fidelity between the technologies investigated is difficult to compare due to their different types, but generally all were of high quality. VR headset and virtual nature room provide a richer information content than TV, thus they can be seen to provide a more vivid experience with same content. However, this relates back to their Surrounding and Inclusive aspects. Thus, based on our study, we would argue that it is the Surrounding and Inclusive aspects that make the difference between the technologies in inducing psychological immersion and presence. In other words, the differences in the amount of surrounding environment, the ability to look in multiple directions, and the extent to which physical reality is shut out seem to be central aspects explaining why higher technological immersion leads to higher psychological immersion and presence.

While it seems obvious that higher technological immersion produces higher psychological immersion and presence, it seems to come with the price of increased VR sickness. Regarding H3a, the participants’ disorientation was higher in the VR headset condition than in the TV condition. However, contrary to the hypothesis, the oculomotor VR sickness was higher in the TV condition than in the VR headset condition. Subsequently, there was no statistically significant difference in the overall VR sickness between the VR headset condition and the TV condition (Table 3; Figure 4). What could explain this finding is what the Virtual reality sickness questionnaire (VRSQ) (Kim et al., 2018) subscales measure. Oculomotor subscale consists of general discomfort, fatigue, eyestrain, and difficulty focusing (Kim et al., 2018). Thus, it is perhaps not that surprising that people find such aspects to be higher when watching a static video from a TV screen than when experiencing the same content with a VR headset that produces higher psychological immersion and presence. Despite the above discrepancy, VR headset was found to be more prone than TV in inducing the disorientation type of VR sickness, that is, headache, fullness of head, blurred vision, dizziness, and vertigo (Kim et al., 2018).

Regarding H3b, the participants' overall VR sickness and disorientation were higher in the VR headset condition than in the virtual nature room condition. There was no statistically significant difference in the oculomotor VR sickness (Table 3; Figure 4). This corroborates previous findings that VR headsets are more prone to cause VR sickness than room-scale solutions (e.g., Martirosov et al., 2022).

Drawing this together, our findings suggest that technologies with high technological immersion lead especially to higher disorientation type of VR sickness than technologies with low or medium technological immersion. We believe that such disorientation type of VR sickness has a more central role than oculomotor type of VR sickness in influencing the attitudes and use intention toward virtual nature delivery technologies, however, further research is needed to affirm this. Thus, while VR headset is better than TV and virtual nature room in inducing psychological immersion and presence, from the VR sickness perspective, it is a worse option.

According to a review by Weech et al. (2019) the evidence generally suggests that there is a negative relationship between presence and VR sickness, meaning that increase in VR sickness would result in lower presence and vice versa. However, the relationship seems to be complex as there are also opposite findings. What might explain the conflicting findings are the numerous different scales used in prior research to measure presence (cf. Schwind et al., 2019) and VR sickness (cf. Weech et al., 2019). Weech et al. (2019) also point out that high technological immersion can increase both presence and VR sickness, which was largely also the case in our study. We further checked whether there were correlations between VR sickness outcomes and overall presence in our data. There was a weak negative correlation between overall VR sickness and presence (−0.152, $p = 0.038$, $N = 186$) and between oculomotor VR sickness and presence (−0.28, $p = 0.0001$, N = 186), whereas between disorientation VR sickness and presence, there was a weak but statistically non-significant positive correlation (0.103, $p = 0.160$, $N = 186$). Hence, based on our findings, we suggest that when investigating VR sickness outcomes or their relationship with immersion and presence, different subscales of VR sickness should be examined.

In practical terms, the significance of immersion and presence have been demonstrated in different virtual nature related contexts. Bolouki et al. (2025) and Litleskare et al. (2020) have suggested that improved presence and psychological immersion would lead to better psychophysiological outcomes of virtual nature. Subsequently, this means that technologies with higher technological immersion could also be more effective in terms of producing psychophysiological benefits during virtual nature exposure. Further, in the context of virtual tourism, presence and psychological immersion have been found to be important determinants of effective experience (cf. Lurdes Calisto & Sarkar, 2024). For example, Tussyadiah et al. (2018) showed that higher presence during virtual nature-based travel experience increases the enjoyment of the experience, which results in stronger preference toward the destination and higher visitation intention. Besides virtual nature experiences, the outcomes of increasing the psychological immersion and presence likely extend to other virtual experiences as well. Thus, different stakeholders working with such products or services should aim to promote psychological immersion and presence in their virtual experiences. To increase the psychological immersion and presence, virtual experience designers should focus on (1) maximizing the amount of surrounding environment, for example by using 360-degree content, (2) supporting the ability to look in multiple directions, for example by using settings that allow it, and (3) shutting out physical reality, for example by using solutions where the visual and auditory presence of physical reality is minimized. However, as the technology producing highest presence and psychological immersion also caused highest disorientation type of VR sickness in our study, the choice of technology likely needs balancing between immersion and presence outcomes and VR sickness. For example, room-scale solutions may be more suitable for longer or repeated virtual experiences, such as recurring exposures in hospitals, therapeutic settings, working environments, or care homes, or for user groups for whom wearing VR headsets causes discomfort. Highly immersive VR headset experiences, despite their greater VR sickness risk, may be justified for shorter, high-impact sessions, where peak immersion would be beneficial. In addition, it is easier to incorporate interactive elements into VR headset experiences to further enhance engagement. Moreover, a room-scale solution is particularly justified in settings where virtual nature experiences are intended to be shared and collectively reflected upon, such as public spaces and leisure or tourism environments. The room may also serve as a supportive environment for additional functions and activities that benefit from virtual nature settings, such as team-based brainstorming, collaborative problem-solving, and various forms of creative work. In contrast, a VR headset would be more appropriate in contexts where privacy or a sense of solitude is desired, for example, in overstimulating or cognitively demanding environments. Finding the equilibrium between effectiveness and VR sickness symptoms in virtual experiences is a challenge that the stakeholders working with virtual experiences need to overcome. Considering this, room-scale solutions seem especially promising.

Nevertheless, it should be noted that virtual nature is a medium and should be regarded as such. It is not aimed to replace actual nature contact, but when immersion and presence can be promoted and VR sickness diminished, virtual nature could support providing similar types of psychophysiological benefits as actual nature.

6. Limitations & future research

The present study comes with some potential limitations. First, participants with an university degree were over-presented (83.9%), and around two-thirds (67.7%) of the sample were women. This places some restrictions on the generalizability. Second, while the participants were almost fully on the same level regarding their previous experience on the use of the investigated technologies, in general, they had very little previous experience with VR headsets and room-scale virtual environments. Future studies could benefit from using a sample that consists of experienced users of such technologies. Third, the present study followed an entirely quantitative approach, and thus, the qualitative aspects of the virtual nature experience were not explored. Future studies could also investigate the qualitative aspects of different virtual nature delivery technologies from the perspective of immersion and presence.

The sensory stimuli used in the present study included visual and auditory. Future research could examine the effects of using olfactory or haptic stimuli in inducing immersion and presence in virtual nature. Finally, in the present study we used a static video. Dynamic videos, that is, videos where the viewer perspective moves in the virtual nature, have been found to be more prone to induce cybersickness (cf. Litleskare et al., 2020). Thus, future research could compare delivery technologies by using dynamic videos. We also used what can be called a cinematic virtual environment utilizing 3-DoF, where the participants only viewed the virtual environment instead of moving in it or interacting with its elements. While this can be seen as a limitation compared to more interactive solutions utilizing 6-DoF, it has the benefit of producing more reliable results when comparing the propensities of the investigated technologies, as movement in or interaction with the virtual environment would be very different when using a TV, VR-headset or a room-scale solution. Thus, conducting the exposure in cinematic virtual environment with 3-DoF allows to minimize confounding factors and to better measure the investigated outcomes. Nevertheless, we acknowledge that using an interactive experience utilizing movement and 6-DoF could provide different kinds of results in terms of the investigated outcomes. This is something we encourage future research to examine. However, that would require a very different kind of scope and experience design from ours; one where the experiment and the material would have to be built accordingly to enable movement in the virtual environment and interaction with its elements.

In the absence of best practice and considering the various virtual nature exposure durations used in previous studies (cf. Browning et al., 2021), we used a 15-minute exposure to allow enough time to experience psychological immersion and presence along with potential VR sickness symptoms. Future studies could investigate the same outcomes using shorter or longer exposure durations. Another potential avenue for future research would be to compare these outcomes between different user groups, for example, among older adults and younger user groups in different settings. Furthermore, dimensions such as social presence, communication with others, embodiment through an avatar, or sending and receiving messages have been found central in technology mediated communication (e.g., Dzardanova et al., 2022). How well they work likely varies between different technologies. However, as the participants in our study were alone in all conditions and had no interaction with other people, these dimensions were not relevant in the case of our study and thus not part of our study design. Future research could investigate these topics through the lens of communication theories.

7. Conclusion

This study enhances the current understanding on how different delivery technologies with varying technological immersion (TV (low), virtual nature room (medium), and VR headset (high)) induce psychological immersion and presence as well as cause VR sickness symptoms in virtual nature. Our findings suggest that the higher the technological immersion is, the higher the psychological immersion and presence outcomes are. It seems that it is especially the differences in the amount of surrounding environment, the ability to look in multiple directions, and the extent to which physical reality is shut out that differentiate these technologies. However, based on our findings the higher psychological immersion and presence produced by higher technological immersion seems to come with the price of increased VR sickness. Our results suggest that technologies with high technological immersion cause especially higher disorientation type of VR sickness than technologies with low or medium technological immersion. Further to these findings, we inform future research by unpacking and providing an exemplar on how to use the terms technological immersion, psychological immersion, and presence in virtual environment research. We also provide practical implications for designers and other stakeholders based on our findings.

Notes

1. The authors disclose that the same study design and procedures have also been used in another study which investigated completely different outcomes (Kari et al. 2024).
2. *With IPQ_INV, data analysis were made in log-scale and these values are back-transformed to data scale describing the ratio of two mean values.
3. *With VRSQ, VRSQ_O, and VRSQ_D, data analysis were made in log-scale and these values are back-transformed to data scale describing the ratio of two mean values.

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Ethical approval

All procedures were performed in compliance with relevant laws and institutional guidelines and have been approved by the appropriate institutional committee. The study was conducted in accordance with the principles of the Declaration of Helsinki. This study received ethical approval from the Ethics Committee for Human Sciences at the University of Turku [Approval number: #52/2022, 16.11.2022]. Respondents gave written informed consent for review and signature before participating in the study. The privacy rights of human subjects were always observed.

Author contributions

CRediT: **Tuomas Kari**: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing; **Ann Ojala**: Conceptualization, Investigation, Methodology, Project administration, Resources, Writing – review & editing; **Mika Kurkilahti**: Data curation, Formal analysis, Methodology, Visualization, Writing – original draft; **Liisa Tyrväinen**: Conceptualization, Funding acquisition, Methodology, Project administration, Writing – review & editing.

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Data availability statement

The anonymized datasets generated during and/or analyzed during the current study will be made openly available in a relevant data repository once the research project has ended.

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