A Tree's Perspective: Enhancing Nature Connectedness Through Transitional and Multisensory Virtual Reality Experiences

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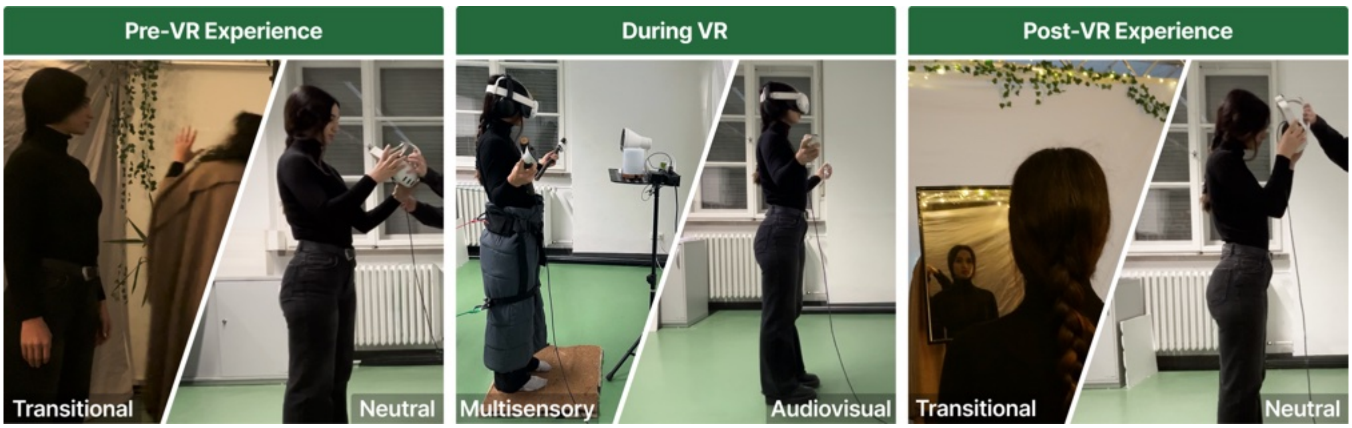

Figure 1: We propose a holistic experience design approach for nature embodiment, incorporating transitional elements (e.g., biophilic design, music, ritualistic performance, post-VR reflection) before and after VR and multisensory enhancements (e.g., weighted blanket, heat lamp, oil diffuser) during VR.

Abstract

Embodying natural entities in Virtual Reality (VR) shows potential to enhance nature connectedness, but design factors that support such embodiment remain underexplored. This study examined whether transitional elements in the physical setting before and after VR and multisensory stimuli during VR can strengthen nature connectedness in a transformative tree-embodiment experience. Through a mixed-methods approach ($N = 20$), where we varied the pre- and post-VR experience (*Neutral* vs. *Transitional*) and sensory modalities (*Audiovisual* vs. *Multisensory*), we found that both transitional and multisensory experiences significantly enhanced presence, embodiment, and nature connectedness, with increases in emotional connectedness sustained one week later. Drawing on interview insights and impact ratings of specific design features, we derive design recommendations for integrating transitional and multisensory elements. Our findings demonstrate the value of holistic design for enhancing the emotional and transformative potential of VR nature embodiment for fostering environmental awareness.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; **Virtual reality**; **Empirical studies in HCI**.

Keywords

human computer interaction, virtual reality, nature connectedness, presence, embodiment, transitions, multisensory, interaction design, transformative experiences, holistic experience design

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1 Introduction

With increasing urbanisation, opportunities for direct nature experiences are declining globally [9, 66]. However, nature experiences can foster mental and physical health [54, 59], while strengthening the emotional bond between urban populations and nature. At the same time, opportunities to design nature interactions emerge through technology in new and creative ways [36], offering the potential of reconnecting individuals with nature to advance environmental stewardship and healthier societies. Nature connectedness (NC), the extent to which individuals feel part of the natural world [41, 57], is strongly associated with wellbeing and pro-environmental behaviour [3, 11, 50], with research on NC gaining increased attention over the past two decades [28].

Immersive virtual reality (VR)[1] has emerged as a tool to enhance the connection to nature [9, 68, 69]. While exposure to virtual nature can be effective in promoting NC, evidence is still limited and largely mixed [9]. Prior work has investigated embodying non-human entities such as animals [1, 39] and trees [68–70], showing that nature embodiment can enhance users' sense of NC [1, 68] and pro-environmental behaviour [68]. However, participants are typically immersed instantly in the VR experience, starting the moment the headset is worn and ending as soon as it is removed. This sudden shift requires users to abruptly adopt a new virtual body, which might not leave enough time for psychological reflection. Therefore, an open challenge in fostering NC is supporting the mental transition into and out of VR [69]. We hypothesise that gradual transitions into and out of the virtual experience, combined with time for reflection, will be more effective than abrupt entry and exit. So far, there is little research exploring holistic VR designs that consider the entire user journey from entering to exiting the physical space. Another key dimension of immersive experience design is the sensory richness during the VR experience. Incorporating multisensory stimuli beyond visuals and audio can enhance users' presence and body ownership [43], both of which have been linked to stronger NC [1, 68]. Yet recent work on tree embodiment found no benefit of multisensory over audiovisual-only VR [68], leaving the effectiveness of multisensory enhancements for nature embodiment uncertain.

Our work addresses this through *I Am a Tree*, a VR experience where immersants embody a tree as the surrounding calm nature turns into a scene of harmful, human-caused nature destruction. We propose a holistic design approach that combines multisensory enhancements (haptic and olfactory) during VR with novel, transitional pre- and post-VR experiences to support smoother transitions into and out of VR, participant readiness, and reflection afterwards. In a within-subject user study ($N = 20$), we examined how these two factors (PrePost: *Neutral* vs. *Transitional*; Modality: *Audiovisual* vs. *Multisensory*) influenced participants' sense of presence, embodiment, and NC.

We found significant main effects for both the pre- and post-VR experience and the sensory modalities on presence, embodiment, and NC, with follow-up survey responses one week later indicating sustained increases in the affective-experiential dimension of NC relative to baseline levels. We report how individual design features were perceived to influence participants' overall experience. Our findings are supported by a thematic analysis of post-experience interviews, providing context for the subjective experience of virtually embodying non-human beings. Overall, our results suggest that embodying a tree in VR offers a novel and powerful perspective for engaging with nature and for fostering increases in NC, with sustained emotional bonds. In the broader context, the findings highlight the value of a holistic design approach, including thoughtfully crafted pre- and post-VR transitions in the physical space and multisensory stimuli during VR, considering the entire user journey from entry to exit. Our study underscores that careful attention to users' psychological state and the physical setting, both before and after a potentially transformative VR experience, can significantly enhance its overall impact. In doing so, this work contributes novel insights into how virtual nature embodiment experiences can be designed for greater psychological impact.

[1]While VR can encompass a range of technologies (e.g., desktop VR, 360° video), in this paper we use the term VR to refer specifically to *immersive VR* (IVR) [61], involving full immersion within the virtual environment, typically achieved through a head-mounted display (HMD).

2 Related Work

For this work, we review five specific areas in the literature to build up to our research gaps and the resulting four research questions.

2.1 Nature Connectedness and VR Interventions

Human-nature connectedness or inclusion in nature, generally referred to as NC, can be defined as the extent to which individuals feel part of the natural world [3, 57] and is often viewed as a multidimensional construct encompassing cognitive, affective, experiential, and behavioural dimensions [41, 46, 57]. NC plays an essential role in both environmental protection [3, 23, 41, 46] and human wellbeing [11, 42, 50], with higher NC linked to more sustainable attitudes and behaviours, and greater psychological wellbeing [3]. While NC can be strengthened through direct nature contact, previous research demonstrates that immersive technologies such as VR can also foster this connection [1, 9, 39, 68, 69], offering immersive and highly controlled environments for experimental studies on NC.

VR experiences can enhance NC and environmental responsibility through scenarios such as cutting down virtual trees [2], examining ocean acidification impacts on coral reefs [39], or embodying animals [1] or trees [68, 70]. Yeo et al. [85] showed that VR environments elicited stronger increases in NC, presence, and positive mood compared to 360° video or TV formats. On the other hand, Brambilla et al. [9] concluded that the overall evidence on the potential of VR to foster NC remains limited and mixed, and the specific design elements that shape VR's effectiveness for fostering NC are not well understood [16]. In addition, most studies assess outcomes immediately after the experience, with only one study including a follow-up measurement of NC [1], pointing to a need for more research on longer-term effects [9].

2.2 Transformative Potential of VR

Transformative experiences are brief, extraordinary moments that can lead to lasting changes in self-conception, personal identity, worldviews, and view of others [15]. Such events entail two key features: epistemic expansion—gaining new perspectives on oneself and the world—and heightened emotional complexity [15]. Chirico et al. [15] proposed VR as a promising medium for eliciting such unique experiences. In this context, Stepanova et al. [75, 76] presented a Transformational Framework, conceptualising transformative experiences as a three-stage process: (i) a novel perceptual experience, (ii) a resulting cognitive shift, and (iii) potential behavioural change (see Figure 2, top).

VR also enables the simulation of impossible or alternative realities [22, 53], providing opportunities for transformation through knowledge expansion. This includes, for instance, experiencing the world from another person's perspective, which may destabilise and reconstruct mental schemes [15]. Khanna et al. [32] identify five technological affordances of VR (immersion, spatial presence, body ownership, engagement, and usability) that appear to mediate empathic and prosocial outcomes in VR perspective-taking research, while emphasising the provisional nature of this conclusion.

Prior work also demonstrated the potential of VR to elicit self-transcendent emotions such as awe [4, 13, 14, 51], though research on designing for transformative experiences remains limited [77]. Kitson et al. [33] identified interaction and design elements for immersive technologies, among those 'nature' and 'embodied' components, that may support positive psychological change in users.

2.3 Virtual Nature Embodiment

Embodied VR presents a promising approach for transformation, as previous research suggests that inhabiting avatars can foster attitude and behavioural change [38]. While most embodiment studies have focused on humanoid avatars, VR also allows for embodiment beyond the human form, offering flexibility in avatar selection [83]. Previous work on nature embodiment in VR has explored different non-human entities, including cows [1], birds [47], turtles [49], corals [1, 39], and trees [68–70], with several studies reporting increases in NC, environmental attitudes, and related outcomes. However, findings have been mixed regarding the role of specific conditions and mechanisms. For example, Markowitz et al. [39] found no significant differences between embodying a natural entity (coral) and a human avatar (scuba diver) on NC, environmental concern or presence, suggesting that the type of avatar alone may not drive changes in NC. Moreover, regarding the sense of presence (i.e., subjective feeling of *being* in a virtual environment [65]), some studies reported that higher presence correlates with greater NC [39, 68], yet others found its mediating role to be limited and temporary [1]. By contrast, embodiment (i.e., the sense of owning the virtual body [44]) appears to play a consistent role. Ahn et al. [1] found that embodiment mediated the effect of VR exposure on NC, with effects persisting one week later. Similarly, Spangenberger et al. [68] observed that embodiment mediated the positive association between presence and NC during tree embodiment. Extending this work, they also found that compassion (particularly when elicited through negative, threatening scenarios) rather than presence or body ownership alone, mediated increases in NC, highlighting the role of affective processes in nature embodiment experiences [70].

Among the various forms of nature embodiment, virtual tree embodiment is a particularly nascent area of research. Initial results were somewhat mixed: Spangenberger et al. [69] found no significant quantitative differences in nature relatedness or perspective-taking between VR and desktop video conditions, though qualitative data indicated stronger self-reflection and self-identification with the tree in VR. Another study supports these reflection outcomes, showing that taking a tree's perspective in 360° VR, combined with a post-VR reflection activity, elicited both observational and empathic reflections from tree and human perspectives [24]. Two subsequent studies by Spangenberger et al. [68, 70] observed significant increases in NC from pre- to post-exposure, suggesting that tree embodiment in VR can enhance users' connection to nature. In this context, we found two existing VR applications that allow users to embody a tree: (1) "TreeSense," developed at MIT's Media Lab, where users start as a seedling and grow into a full tree, with electronic muscle stimulation for tactile stimulation [37]; and (2) "Tree", a more advanced VR film version of TreeSense, developed at MIT Media Lab in collaboration with film directors, and used as stimulus material in studies by Spangenberger et al. [68–70].

Adjacent to this tree-embodiment work, a recent study by Ye et al. [84] describes a dynamic, multisensory VR plant-growth game grounded in embodied interaction design. Instead of directly embodying a plant or tree, players interact with a rope-based interface to control a tree's energy flow and defend it from harsh environmental conditions.

2.4 Multisensory Enhancements in VR

Given the relevance of presence and embodiment in fostering NC, multisensory stimuli may play a key role in enhancing the effectiveness of nature embodiment. Multisensory feedback, compared to audiovisual-only, is known to enhance presence and task performance in VR [43]. Tactile sensation has been linked to increased embodiment [17, 20], and thermal and wind cues can increase realism and spatial presence [12, 26]. Olfactory stimuli have also been associated with increased presence [45] and reduced stress in virtual nature settings [25, 55]. However, multisensory input can occasionally increase cognitive load [19] or be perceived as disturbing [79], underscoring the importance of credible, well-integrated stimuli. Furthermore, a recent study on virtual tree embodiment by Spangenberger et al. [68] found no benefit of multisensory enhancements on presence or NC compared to audiovisual-only VR. Finally, a review identified several key gaps in the literature: (i) a lack of multisensory feedback beyond audio, visuals, and vibrations; (ii) limited exploration of how touch sensations beyond visual-tactile stimulation influence embodiment; and (iii) a predominant focus on task performance rather than users' subjective perception or emotional responses [43]. Moreover, research on the psychological outcomes of multisensory VR in the specific context of virtual nature remains scarce [72]. These gaps limit our understanding of how multisensory design can best support nature embodiment.

2.5 Transitions into and out of VR

Another potential approach to enhance embodied experiences involves transitions into and out of VR, which remain underexplored in HCI research. While virtual, transitional environments, such as virtual room replicas, have been generally shown to increase presence [29, 74, 80], most studies overlook the potential influence of participants' state of mind and real-world experiences before and after VR. Here, an HCI trajectories framework emphasises the relevance of coherent, continuous journeys throughout an interactive user experience, for instance recommending traversals

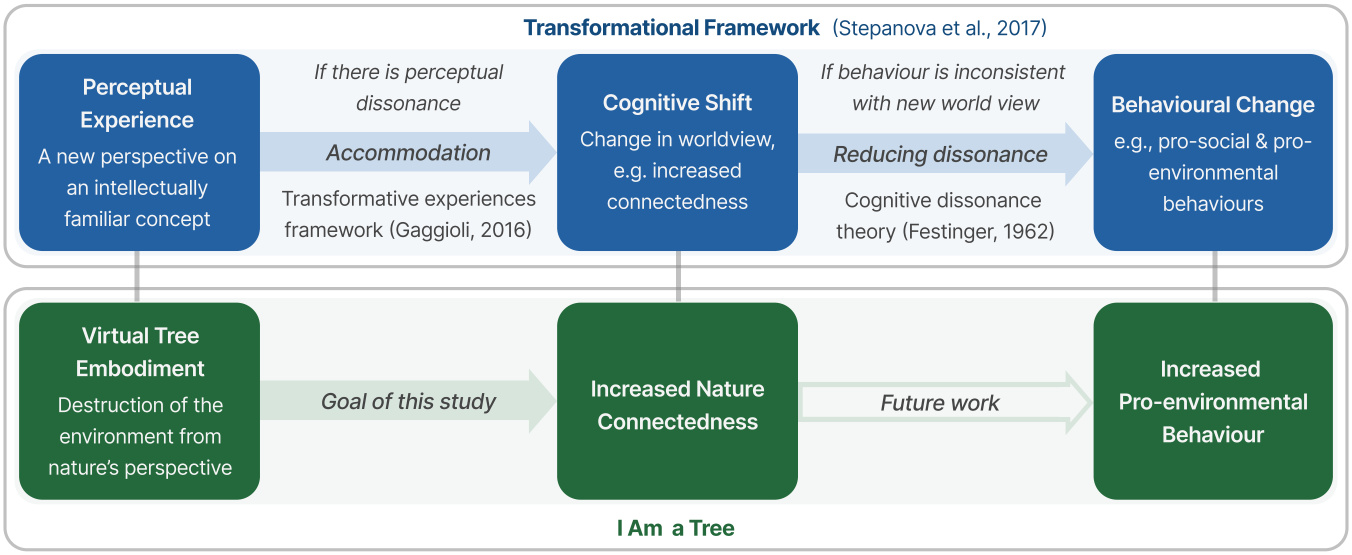


Figure 2: Conceptual idea of *I Am a Tree*, applied to the Transformational Framework's three stages: Virtual tree embodiment (perceptual experience) to enhance NC (cognitive shift), and, ultimately, promote pro-environmental behaviour (behavioural change). The framework at the top is adapted from Stepanova et al. [75], with permission from the authors.

Table 1: Overview of primary related work that guided the design of our VR experience and user study, listing the topic, key literature, and key design implications for our work.

Topic	Key Literature	Key Design Implications	Concrete Design Choices
Transformative experiences	[75–77]	Novel perceptual perspective to evoke a cognitive shift (e.g., increased connectedness)	Taking nature's perspective by embodying a tree
Multisensory VR	[43, 69]	Olfaction and haptics beyond vibration to increase presence and embodiment	Combination of nature-related smells, kinesthetic and tactile haptics (see Table 2)
Transitions into/out of VR	[5, 29, 73, 74]	Holistic design of the complete experience; traversals between real and virtual; gradual transitions to increase presence; reflection-promoting ending	Several pre- and post-VR transitional phases to provide a holistic user experience (see Figure 4); walking into a different room section through a curtain; triggering post-VR (self-)reflection through a mirror and a reflective interview
Set and setting, biophilic design	[27, 34]	Calming, biophilic pre-/post-VR setting with ritualistic and foreshadowing elements	Calm background music, dimmed lighting with fairy lights, foreshadowing nature decoration (e.g., plants, twigs, acorns, pine cones); poem recitation in a ritualistic performance
Virtual nature embodiment	[1, 39, 68–70]	Nature embodiment and threatening scenario to increase NC; multisensory effectiveness unclear	Embodying a tree while the virtual scene transitions from a calm setting to threatening nature destruction; multisensory enhancements during VR

between real and virtual worlds and reflective endings [5]. Moreover, a qualitative study identified five themes (space, control, time, sociality, and sensory factors) that may shape the experience of exiting VR and discussed ways to either heighten or soften this exit transition. For example, participants suggested a softer transition before taking off the HMD by fading into a see-through mode [35]. Two participants also mentioned modifications to the real-world environment, specifically in the physical and social setting.

Drawing on a case study on profound VR experiences, both set (user's mindset) and setting (physical and social context) may play a crucial role in helping users transition into another reality [34]. The authors propose these factors as essential design components, suggesting they can enhance presence, pro-sociality, and creativity, for instance, by adding 'foreshadowing elements' in the physical environment to create a sense of continuity between the real and virtual world. Moreover, they suggest the use of ritualistic elements before entering VR to set the tone and evoke profound experiences [34]. As these insights are based on qualitative data, the impact of such transitional design elements has yet to be statistically validated.

Educational technology research has examined how to orchestrate VR learning sessions in classroom settings through purposeful activities before and after the VR experience [21, 48, 71]. This work shows that structuring the broader learning sequence around VR (e.g., through preparatory learning materials, guided exploration, and post-VR reflection) can influence outcomes: for example, adding a written self-explanation task after a VR biology lesson did not yield additional learning benefits [21], whereas an electrical engineering lesson orchestrated around a VR learning application, including additional learning material and reflective activities, enhanced knowledge and comprehension gains compared to non-VR group work [71]. While this literature focuses on educational contexts, it overall suggests that the effectiveness of a VR experience may be shaped in part by the settings and activities surrounding it.

2.6 Research Questions

The analysis of previous work revealed that VR research to foster NC has seen significant growth and highlighted the potential of embodying non-human entities, such as trees. Nevertheless, several areas remain underexplored: (1) the influence of pre- and post-VR transitions in the physical space on participants' experiences; (2) the role of multisensory enhancements beyond audiovisual stimuli in supporting the embodied experience; (3) understanding which specific design features are effective in supporting transformative experiences for connectedness; and (4) the longer-term effects of virtual nature embodiment. Addressing these gaps is essential for further advancing VR as a tool for fostering environmental awareness and connectedness. To this end, we set out to extend prior findings on tree embodiment and investigated the following research questions.

RQ1 While virtual, transitional environments that ease users into VR have been shown to enhance presence [74], the role of users' pre- and post-VR experiences, shaped by state of mind and physical setting [34], remains unexplored in virtual nature embodiment. Therefore, we pose our first research question: *How do pre- and post-VR experiences influence presence, embodiment, and nature connectedness?*

RQ2 In a wide range of applications, sensory modalities have been shown to be beneficial in connecting with virtual environments [43]. However, in the context of tree embodiment, prior work recently found limited effects of multisensory enhancements on presence and NC [68]. Thus, we pose our second research question: *How do sensory modalities during VR influence presence, embodiment, and nature connectedness?*

RQ3 While core technological affordances of VR (e.g., spatial presence, body ownership) may mediate empathic outcomes in VR perspective-taking [32], such effects are often difficult to attribute to specific design aspects in prior work. Similarly, little is known about which specific design features are effective in fostering transformative VR experiences for connectedness. To address this, we also ask: *Which specific design features or elements, both transitional and multisensory, have the strongest impact on participants' overall experience?*

RQ4 Finally, to our knowledge, only one previous study [1] has included a follow-up measurement after nature embodiment in VR, highlighting a significant knowledge gap regarding whether and how responses may persist beyond the immediate session. Accordingly, we ask our final research question: *Does the overall VR intervention lead to sustained effects on nature connectedness one week after the study?*

3 Experience Design

In this work, we go beyond the state-of-the-art and propose a holistic experience design approach for VR that, based on our research questions, encompasses the entire user journey from (1) the pre-VR experience, (2) through various sensory enhancements during VR, (3) to the post-VR experience (see Figure 1), to fully realise the transformative potential of nature embodiment.

3.1 VR Application: I Am a Tree

To explore this, we developed a novel VR application called *I Am a Tree* following an iterative design process with pilot testing. Rather than embodying another person, it enables immersants to experience a sense of being a tree, perceiving environmental destruction from nature's point of view and experiencing climate change as an immediate, personal threat. Based on our literature review, we synthesised key design implications that informed both the overarching concept and the design of the VR experience (see Table 1). Grounded in Stepanova et al.'s transformational VR framework [75, 76], *I Am a Tree* aims to foster cognitive shifts towards nature connectedness. We illustrate our conceptual idea in Figure 2, mapping it onto the framework's three stages.

The final VR application comprises three scenes (see Figure 3):

(1) **Prologue**: It begins in a dimly lit forest at dusk, guided by a narrated poem, aimed at slowly introducing the transformation into a tree. The immersant is prompted to step forward, triggering a gradual transition into the main scene.
(2) **Main Scene – Forest Clearing**: In a mixed European forest, the immersant now embodies a large oak tree through visuals, narration, control of two branches, and subtle tree bending that responds to the user's head movements, overlooking a vibrant daytime forest clearing. Then, the calm, lush environment with birds, a river and greenery suddenly transforms into *Destruction of Nature*, as industrial structures, waste, smoke, fire, and storms gradually overtake the landscape.
(3) **Outro Reflection**: From a second-person perspective, the immersant sees the oak tree now barren, both floating in outer space, accompanied by narration and classical music, aiming to provide time for reflection.

A script of the narration can be found in the Supplementary Material. Following a holistic design approach, we then integrated both pre- and post-VR transitions and multisensory in-VR enhancements to foster cognitive shifts towards nature connectedness at both emotional and reflective levels.

3.2 Pre- and Post-VR Transitions

We created pre- and post-VR transitions that extend beyond in-headset transitional environments seen in prior work (see Section 2) and instead actively shape the atmosphere and participants' mental state in the physical environment. In the context of transformative

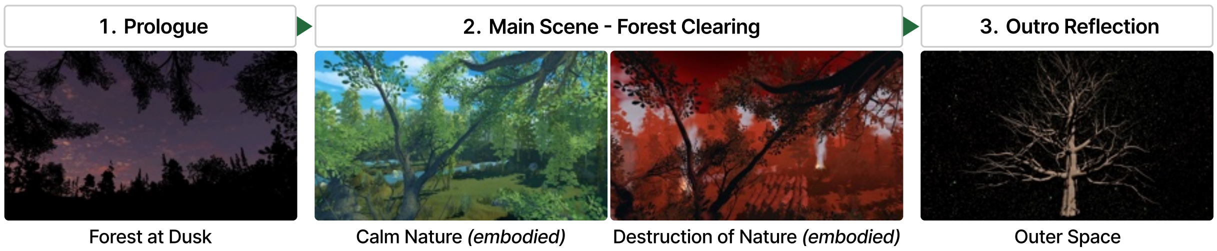


Figure 3: The three VR environments, shown from the user's perspective: (i) Prologue, (ii) Main Scene in a forest clearing, starting with peaceful, calm nature, followed by environmental destruction, and (iii) Outro Reflection.

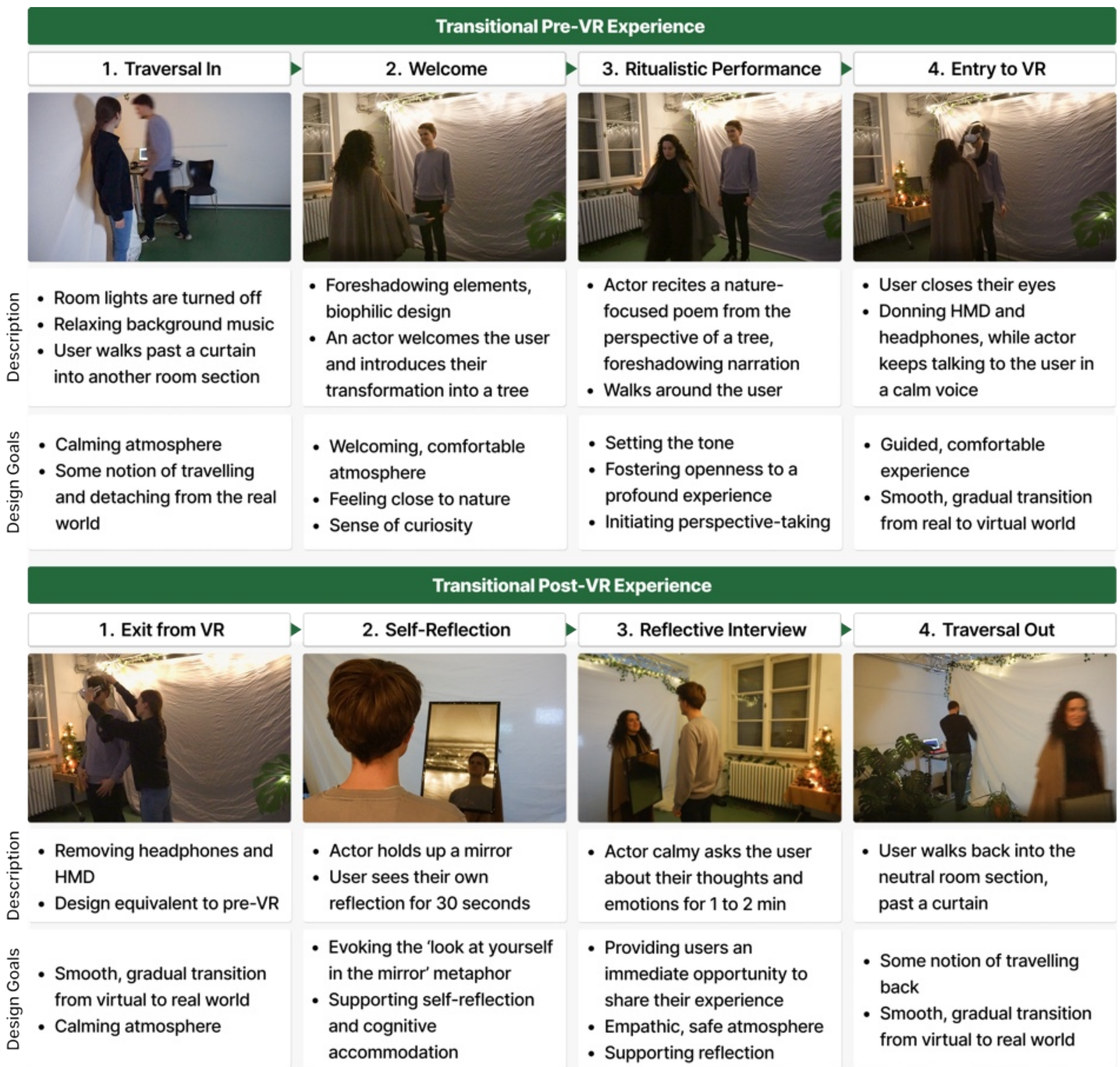


Figure 4: Transitional phases during the pre- and post-VR experience, presenting images, descriptions, and design goals for each. See poem text for the Pre-VR transition in the Supplementary Material.

VR experiences, where we aim to evoke profound emotional responses and shifts in worldviews, we sought to prepare participants to be more open and receptive before entering VR, and to provide space for reflection afterwards.

The real-world transitions therefore combine several elements informed by related work on set and setting and foreshadowing elements [34], and transformative experience design (see Section 2.2). Figure 4 illustrates the specific transitional phases with their associated design goals. Specifically, the pre-VR phases incorporate biophilic design (nature-inspired decorations such as plants, leaves, acorns, and twigs), dimmed lighting and calming music, actor guidance, and ritualistic elements, including a nature-themed poem recitation (see narration script in the Supplementary Material). These design choices aim to ease participants into the embodied experience, provide continuity between the physical room and the upcoming forest scene, and foster an open state of mind. In line with previous suggestions that traversals can reinforce presence by evoking a sense of "travelling" into another world [73], participants walk through a curtain into a dedicated transitional space. The post-VR phases aim to guide participants back into the physical room and support reflection on the experience. A mirror is used as a symbolic cue to help users process the transition out of VR and consider their own role in the human–nature relationship. Providing this reflective space aligns with frameworks of transformative experience that emphasise cognitive accommodation and integration as essential steps towards behavioural change [76].

Together, these pre- and post-VR phases are designed to (i) smooth the transition into and out of VR, (ii) enhance presence, embodiment, and nature connectedness even beyond the headset, and (iii) support reflection as a potential catalyst for transformation.

3.3 Multisensory Enhancements during VR

Building on prior research showing that congruent stimulation across modalities can enhance presence and body ownership [43] (see Section 2), the experience also includes multisensory enhancements during VR. These enhancements include carefully selected olfactory and haptic cues (tactile, kinesthetic, wind, and thermal), thereby overall engaging the senses of sight, hearing, smell, and touch (including thermoception). We prioritise smell and touch (beyond vibrations), as these modalities are rarely incorporated in VR yet can strongly support presence, embodiment, and affective responses [43]. Our design aims for stimuli that are perceptually realistic, align with the virtual environment and narrative, and reinforce the sensation of embodying a tree. By designing congruent, contextually appropriate cues, we seek to strengthen immersion and embodiment without distracting from the central perspective-taking goal. Multisensory cues were explicitly designed to be synchronous with the corresponding virtual scene (e.g., heat and smoke smell start during the fire scene, matching VR visuals and narration), as asynchronous timing or mismatched stimuli risk breaking presence and embodiment [7, 63]. Overall, our olfactory cues primarily aim to heighten emotional responses and the sense of being there in the environment, while haptic stimuli are mainly intended to ground the experience in the body, supporting both presence and embodiment. For example, a weighted blanket around the user's hips aims to evoke a sense of heaviness and groundedness, resembling a tree, while simultaneously reducing their sense of agency by constraining movement. The warmth of an infrared lamp and the subtle smell of smoke are used to reinforce the sensation of fire and danger, manually applied airflow simulates stormy wind in the forest, and brief, congruent touches of leaves brushing the user's hand aim to enhance body ownership. Table 2 summarises all multisensory stimuli used in our experience, including their modalities, design goals, and targeted variables, and is complemented by a VR cue timeline that illustrates how they are integrated and timed with in-VR visuals and audio (see Supplementary Material).

We next describe our user study evaluating the impact of this holistic experience design, including the transitional and multisensory elements.

4 Methods

To answer our research questions, we performed a controlled, within-subject experiment on the *I Am a Tree* application, systematically varying the pre- and post-VR experience and the sensory modalities during VR.

4.1 Study Design

Our experiment followed a 2×2 factorial design with two independent variables, each with two levels (see Figure 5):

- PrePost *(Neutral* vs. *Transitional)*: The pre- and post-VR experience was either *Neutral* (i.e., no real-world transitions, taking place in a standard laboratory setting, guided by an experimenter and reflective post-VR questions neutrally asked by the experimenter) or *Transitional* (i.e., including real-world transitions before and after VR, taking place in a calm, biophilic setting, guided by an actor and reflective post-VR questions asked by the actor in an empathic way; as described in Section 3.2).
- Modality *(Audiovisual* vs. *Multisensory)*: The in-VR experience was either *Audiovisual* (i.e., only visual and auditory cues provided through the HMD) or *Multisensory*, augmenting audiovisual VR with haptic (kinesthetic and tactile sensations, including wind and temperature change) and olfactory stimuli, as described in Section 3.3.

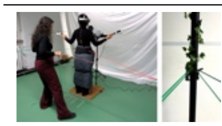
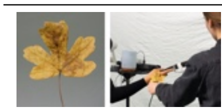
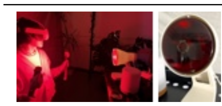
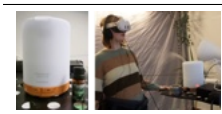
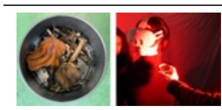
This design resulted in four experimental conditions (see Figure 5). We systematically examined the two factors to determine their individual and combined effects on self-reported sense of presence, level of embodiment, and NC. In addition, we explored the impact of specific design features and investigated the effects of the overall VR intervention on NC at a one-week follow-up.

As summarised in Table 3, all conditions utilised the same core *I Am a Tree* VR application, including identical virtual environments, in-VR audio, branch control and tree bending elements (as described in Section 3.1). Participants were able to control the virtual branches by moving tracked real tree branches in *Multisensory* conditions and standard VR controllers in *Audiovisual* conditions.

4.2 Measures

We adopted a mixed-methods approach, combining quantitative self-report questionnaires (see Supplementary Material for all scales)

Table 2: Design goals and descriptions of haptic and olfactory enhancements used in *Multisensory* conditions. Timings of the different stimuli are documented in the Supplementary Material. In-VR visuals and audio were identical across all conditions.

Image	Description	Modality	Design Goals	Target
	**Tree branches:** Held in both hands. Tracked movement controls virtual branches.	Tactile (texture), Kinesthetic (weight)	Sense of touching bark, embodied experience of being a tree, feeling close to nature.	Embodiment, NC
	**Textured mat:** Stepping onto the mat in socks. 1 layer coconut fiber, 1 layer hemp.	Tactile (texture)	Sense of standing on a soft (hemp) and textured (coconut fiber) forest ground. Feeling close to nature.	Presence, Embodiment, NC
	**Weighted blanket:** 6kg blanket surrounding participants' hips and legs. Attached with straps.	Tactile (pressure), Kinesthetic (weight)	Sense of heaviness, feeling grounded like a tree. Movement confinement emphasises trees' lack of agency -> Sense of immobility and helplessness.	Embodiment
	**Swaying movement:** Side-to-side motion, increasing in strength. Manually applied to participants via 4 ropes.	Kinesthetic (movement, position, balance)	Sense of slightly swaying in the wind (Calm Nature). Sense of being pulled and attacked (Destruction), matching the narrative's dynamics.	Embodiment
	**Touch of leaves:** Slightly brushing past participants' right hand twice.	Tactile (brief pressure, texture)	Congruent touch synchronised with in-VR visuals and sound to increase body ownership.	Embodiment
	**Wind:** Manually provided airflow using a piece of cardboard, targeting the upper body, increasing in speed.	Tactile (aerodynamic)	Sense of being there in the storm.	Presence
	**Heat:** Automated infrared lamp, targeting participants' upper body.	Tactile (thermal)	Sense of being there close to the fire. Sense of danger.	Presence
	**Pine smell:** Automated oil diffuser. 6 drops of pine essential oil in 1 cup of water.	Olfactory	Sense of being there in the forest, amidst trees.	Presence, NC
	**Smoke smell:** Real burnt twigs and leaves, manually held under participants' face.	Olfactory	Sense of being around fire. Sense of danger.	Presence

with qualitative interviews to capture participants' psychological and experiential responses.

4.2.1 *Presence.* We assessed participants' sense of presence using the three-item Slater-Usoh-Steed (SUS) short form [64], covering feelings of *being there* in the virtual environment, realism, and the extent to which the VR world was somewhere they visited or something they saw. Items were rated on a 7-point Likert scale.

4.2.2 *Embodiment.* We measured perceived embodiment with a modified 13-item embodiment scale [1, 62], adapted for tree embodiment following previous work [68] and for tactile leaf contact present in our study (see Supplementary Material). On a 5-point Likert scale, it measures the extent to which participants felt that the virtual tree body was their own body, covering three dimensions of embodiment: embodiment-body (e.g., "How much did you feel that the tree body was your body?"), embodiment-touch (e.g., "How strong was the feeling that the touch you felt was caused by the leaves you saw?"), and embodiment-emotional involvement (e.g., "To what extent did you feel scared at the thought that your tree body would be harmed?") [68].

4.2.3 *Nature Connectedness (state).* We assessed NC with two complementary state measures as they capture different dimensions of the construct. Following related work (e.g., [1, 49, 67, 68, 70, 85]), we used the single-item Inclusion of Nature in Self (INS) scale, a pictorial Venn-diagram measure, to capture the *cognitive* aspect of NC [56]. On the 7-point scale, responders choose the diagram that represents their sense of interconnection with nature. We instructed participants to refer to their state in the current moment ("How connected do you feel with nature right now?") [68, 70]. However,

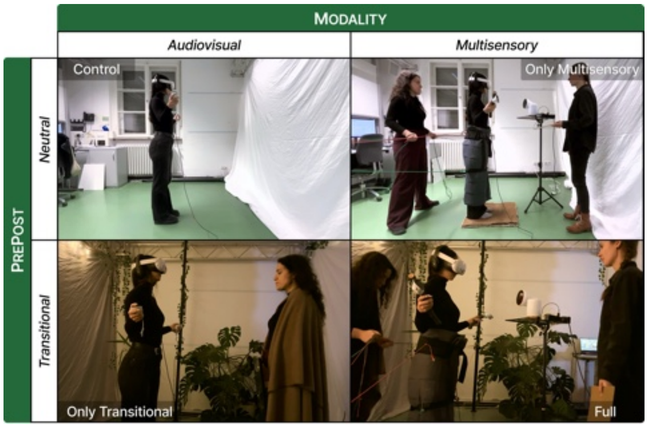


Figure 5: Experimental context and physical setup across all four conditions, illustrating variations in (i) the setting of the pre- and post-VR experience *(Neutral vs. Transitional)*, and (ii) the sensory modalities during VR *(Audiovisual vs. Multisensory)*.

Table 3: Summary of features present in the four experimental conditions. All conditions used the same VR environment and in-VR audio. The *Only Transitional* (OT) condition included all transitional features but not the haptic or olfactory features; the *Only Multisensory* (OM) condition included all multisensory features but no transitional features; and the *Full* (F) condition included both feature sets, while the *Control* (C) condition included neither.

	C	*OT*	*OM*	*F*
VR environments from Figure 3	✓	✓	✓	✓
In-VR audio feedback	✓	✓	✓	✓
All transitional features from Figure 4		✓		✓
All multisensory features from Table 2			✓	✓

this pictorial scale relies on participants' ability to mentally abstract their relationship with nature [41] and, as a single item, its reliability cannot be assessed [58]. To address these issues and to also capture the *affective–experiential* dimension of NC, we supplemented it with the validated 14-item Connectedness to Nature Scale (CNS) [41], an approach used in prior VR-nature work [67]. The CNS measures individuals' momentary sense of oneness with the natural world on a 7-point agreement scale (e.g., "At the moment, I'm feeling that the natural world is a community to which I belong." and "Right now, I am feeling deeply aware of how my actions affect the natural world.").

4.2.4 Impact Ratings. After all conditions, we administered a custom impact questionnaire (see Supplementary Material) in which participants rated specific design features on a scale from −4 (very strong negative impact) to +4 (very strong positive impact). Ratings were grouped by pre-/post-VR experience, multisensory in-VR stimuli, and general VR experience. Participants could indicate if they had not noticed a feature or add and rate up to three additional aspects per category.

4.2.5 Qualitative interviews. We conducted semi-structured exit interviews to gain a deeper understanding of participants' individual experiences during the study, primarily exploring participants' perceptions of the pre-/post-VR experience and multisensory elements, including the most impactful elements, emotional effects, perceived influence on NC, and ideas for improvement (see interview script in the Supplementary Material). Follow-up prompts encouraged reflection on specific experiential details and emotional responses.

4.2.6 Additional Measures. In addition to our key dependent variables, we also assessed motion sickness using the single-item Fast Motion Sickness scale (FMS) [31] on a slider ranging from 0 (no sickness at all) to 20 (severe sickness), and affective wellbeing using the ten-item International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) [78]. Additionally, participants filled out a written reflection task after each condition, aimed at assessing their empathic responses. Before the study, we measured participants' NC as an individual trait using the trait version of the 14-item CNS scale [41]. In a follow-up survey, we also measured participants' personality using a ten-item short form of the Big Five Inventory (BFI-10) [52]. As the wellbeing, trait NC, personality, and reflection measures were not central to our research questions, we do not report their results in this paper.

4.3 Apparatus

The *I Am a Tree* VR experience, developed in Unity (2022.3.32f1) with three Universal Render Pipeline (URP) scenes, was used as stimulus material across all conditions. The environmental changes during the *Destruction of Nature* phase were achieved through dynamic placement of industrial objects and waste (introduced one by one when the user is not looking), physics-based tree falling, particle effects for smoke and fire, spatial audio, and lighting and fog transitions from a sunny blue day to a stormy red sky. In *Multisensory* conditions, heat and smell stimuli were automated via an open-source smart home platform, Home Assistant, running on a Raspberry Pi. An infrared heat lamp was connected through a smart Wi-Fi plug (Tapo P100) and an oil diffuser was controlled by a relay (Songle SRD-05VDC-SL-C) and an ESP32-S3-Zero microcontroller running ESPHome. Both were triggered from Unity via HTTP requests.

For the study, the laboratory was divided into two sections of approximately equal size ($3m \times 2m$). One served as a standard lab setting for *Neutral* conditions, surveys, and interviews, while the other, separated by a curtain and decorated with biophilic elements and fairy lights, was used exclusively for the *Transitional* conditions. The application was deployed on a Meta Quest 3 HMD (2064×2208 pixels per eye, $110° \times 96°$ field of view, Qualcomm Snapdragon XR2 Gen 2 processor, 8 GB RAM) connected via a Meta Link cable to an ASUS TUF Gaming F15 laptop (12th Gen Intel Core i5-12500Hm processor, NVIDIA GeForce RTX 3050 GPU, 16 GB RAM, 475 GB SSD) running Unity. Two sets of Quest 3 controllers were used: one handheld in *Audiovisual* conditions and one attached to the tree branches in *Multisensory* conditions. Participants wore noise-cancelling headphones (Bose QuietComfort) to block real-world sound. Online surveys were administered via Qualtrics.

4.4 Study Procedure

Before the in-person session, participants completed an online pre-survey collecting demographics and nature-related characteristics. At the lab, participants received study information, gave informed consent, and completed baseline questionnaires (INS, CNS, I-PANAS-SF, FMS) on a laptop. The experimenter then gave information on the VR experience and reminded participants that some conditions would include physical touch. Following a within-subject design, each participant then experienced all four VR conditions. We chose a within-subject design to enable participants to directly compare conditions and provide detailed feedback on how pre-/post-VR transitions and multisensory stimuli affected their experience. Moreover, individual participant characteristics are controlled for in this design, which allows the attribution of outcomes to differences in conditions rather than differences between subject groups. Although we acknowledge that repeated exposure to the "I Am a Tree" experience made participants aware of the storyline and introduced the risk of carryover effects, this trade-off was acceptable given the richer comparative insights gained in interviews. Order effects were minimised by counterbalancing condition orders across participants using a balanced Latin square [8].

Each VR session lasted approximately 6 minutes (7 to 10 minutes including transitional phases). After each condition, participants filled out post-condition questionnaires (INS, CNS, I-PANAS-SF, SUS, Embodiment, FMS) on a laptop and a written reflection task on paper. Following the final condition, participants completed an online post-survey, including impact ratings of specific design features, and took part in a semi-structured interview that lasted 15 minutes on average. In total, the in-person study lasted on average 113 minutes, ranging from 87 to 165 minutes. Seven days later, participants were invited to complete a follow-up survey assessing NC (INS, CNS) and wellbeing (I-PANAS-SF).

4.5 Data Analysis

4.5.1 Quantitative Analysis. We used Python (3.12.1) to process and R (4.4.2) to statistically analyse the survey data. From multi-item Likert-scale responses, we computed scale scores (SUS, Embodiment, CNS state). For state NC measures, we then calculated within-subject change scores (ΔINS, ΔCNS) by subtracting baseline from post-condition values to control for individual baseline differences [68, 69]. All tests used a significance level of $\alpha = .05$. To address RQ1 and RQ2, we conducted two-way repeated-measures analyses of variance (RM ANOVAs) with within-subject factors Pre-Post and Modality on each dependent variable: presence, embodiment, ΔINS and ΔCNS, as well as motion sickness. As the data were non-normally distributed according to Shapiro-Wilk tests, we performed non-parametric factorial analyses using the Aligned Rank Transform [82], followed by RM ANOVA on the aligned-ranked data. We report partial eta squared (η_p^2) as a measure of the effect, which can be categorised as small ($\geq .01$), medium ($\geq .06$), or large ($\geq .14$) [18]. Regarding RQ3, we compared overall impact ratings using a paired t-test with Cohen's d_z as effect size. To test for lasting effects (RQ4), we compared baseline to one-week follow-up for INS and CNS state scores, conducting Wilcoxon signed-rank tests with rank-biserial correlation r as effect size for non-parametric data; or otherwise, paired t-tests with Cohen's d_z. Based on Cohen's guidelines [18], $|r|$ is classified as a small ($\geq .1$), medium ($\geq .3$), or large ($\geq .5$), and d_z as a small ($\geq .2$), medium ($\geq .5$), or large ($\geq .8$) effect size. Negative values indicate adverse effects.

4.5.2 Qualitative Analysis. We conducted qualitative analysis of the exit interviews to gain insights into participants' experiences, focusing on RQ1–RQ3. After transcribing the interview recordings in Whisper (v0.0.15), we conducted a hybrid deductive–inductive thematic analysis [10] using ATLAS.ti (v25.0.1.32924). Our process involved: (i) inductive open coding of 100% of the data by one researcher, yielding 937 initial codes; (ii) deductive construction of six main themes, informed by research questions RQ1 and RQ2; (iii) categorisation of initial codes into the themes, through collaborative discussion among three researchers until consensus was reached; (iv) fine-grained inductive analysis within each theme to group and refine codes, again through collaborative discussion, resulting in 37 final codes; and (v) final review and application of final codes across the dataset to ensure consistency. This hybrid approach enabled us to capture participants' detailed, diverse experiences while structuring the insights around our research questions.

4.6 Participants

The study received approval from our university's ethics board. We recruited 25 participants via an institution's mailing list and compensated them with an equivalent of approximately 14 USD per hour. Data from 5 participants were excluded (one after a scene modification, two for not following instructions, one due to accidentally turning off the HMD, one due to sound issues), leaving 20 participants for analysis. This sample size was well-suited to our mixed-methods approach, enabling reliable within-subject comparisons while also allowing for in-depth qualitative exploration in interviews. Participants were engaged in the in-person study for an average of 113 minutes.

Of the 20 participants, 12 identified as female, 8 as male, and 0 as non-binary, aged 20–34 years ($M = 24.65$). Sixteen participants were students. Prior VR experience was mixed, with participants who had never used VR (3), who used it rarely (8), i.e., 1–3 times, occasionally (5), i.e., 4–9 times, sometimes (2), i.e., 10–19 times, or frequently (2), i.e., 20–49 times, with none reporting very or extremely frequent use. Time spent in nature was reported as daily (2), weekly (10), monthly (7), or rarely (1). Current living area was described as urban (12), suburban (5), or provincial (3), with none rural. Environmental concern varied, reported as not at all (1), slightly (3), somewhat (1), moderately (6), concerned (5), very (2), or extremely concerned (2). Trait NC (CNS) averaged $M = 3.45$ ($SD = 0.56$, $min = 2.29$, $max = 4.50$) on a 1–5 scale, comparable to the general public in prior work [41].

5 Results

Next, we present our quantitative and qualitative analysis, addressing our four research questions. For RQ1 and RQ2, Table 4 shows descriptive results, Table 5 statistical analyses, and Figure 6 and Figure 7 their visualisations. Self-reported motion sickness across

Table 4: Descriptive statistics of post-condition outcomes for each level of the independent variables.

	PrePost						Modality					
	Neutral			*Transitional*			*Audiovisual*			*Multisensory*		
	M	**SD**	**Mdn**	**M**	**SD**	**Mdn**	**M**	**SD**	**Mdn**	**M**	**SD**	**Mdn**
Presence	4.33	1.79	4.33	5.06	1.72	5.67	3.98	1.62	4.33	5.41	1.66	6.00
Embodiment	2.79	1.14	2.88	3.07	1.06	3.08	2.31	0.89	2.04	3.54	0.94	3.69
ΔINS	1.33	1.47	1.00	1.95	1.60	2.00	1.15	1.33	1.00	2.13	1.64	1.50
ΔCNS	1.11	1.05	1.00	1.51	1.09	1.19	1.04	.90	1.00	1.58	1.19	1.31
FMS	.93	1.53	.00	.85	1.51	.00	.98	1.69	.00	.80	1.32	.00

Note: M = Mean, SD = Standard Deviation, Mdn = Median, ΔINS = Change in Inclusion of Nature in Self (state), ΔCNS = Change in Connectedness to Nature scale (state), FMS = Fast Motion Sickness scale. Changes refer to differences between baseline and post-condition measurements.

Table 5: Inferential statistics of post-condition outcomes, including Shapiro-Wilk normality tests and two-way ART RM ANOVAs ($F(1,57)$). Partial ETA squared (η_p^2) is reported as the effect size. Significant effects below $\alpha < 0.05$ are bolded.

	Normality		PrePost			Modality			PP × M		
	W	**p**	**F**	**p**	η_p^2	**F**	**p**	η_p^2	**F**	**p**	η_p^2
Presence	.93	**<.001**	14.23	**<.001**	.20	50.21	**<.001**	.47	.31	.581	.01
Embodiment	.96	**.019**	4.84	**.032**	.08	89.35	**<.001**	.61	.39	.536	.01
ΔINS	.93	**<.001**	10.10	**.002**	.15	27.64	**<.001**	.33	.06	.808	.00
ΔCNS	.95	**.006**	5.37	**.024**	.09	11.47	**.001**	.17	.15	.695	.00
FMS	.65	**<.001**	1.03	.314	.02	.40	.528	.01	.71	.404	.01

Note: ΔINS = Change in Inclusion of Nature in Self (state), ΔCNS = Change in Connectedness to Nature scale (state), FMS = Fast Motion Sickness scale. Changes refer to differences between baseline and post-condition measurements.

all conditions was M = 0.89 (SD = 1.51) on a scale from 0 to 20, with no significant main or interaction effects of the independent variables observed (see Table 4 and Table 5), suggesting that motion sickness did not influence the study outcomes.

5.1 Effects of PrePost and Modality

5.1.1 Sense of Presence. For the SUS presence questionnaire, the ART RM ANOVA showed significant main effects of PrePost and Modality on SUS mean scores, both with a large effect size. Presence ratings were significantly higher in *Transitional* conditions compared to *Neutral* conditions, and in *Multisensory* conditions compared to *Audiovisual* conditions.

5.1.2 Embodiment. Regarding the extent to which participants had a sense of embodying the tree, the ART RM ANOVA showed a significant main effect of PrePost on the level of embodiment, with a medium effect size. Similarly, it also showed a significant main effect of Modality on the level of embodiment, with a large effect size. Embodiment ratings were significantly higher in *Transitional* conditions compared to *Neutral* conditions, and in *Multisensory* conditions compared to *Audiovisual* conditions.

5.1.3 Nature Connectedness. To assess participants' state NC, we examined changes in INS and CNS after each condition, where positive values represent an increase and negative values a decrease in NC (see Figure 6). For the INS scale, ART RM ANOVAs revealed significant main effects of PrePost and Modality on ΔINS, both with a large effect size. Similarly, the ART RM ANOVA showed a significant main effect of PrePost on ΔCNS, with a medium effect size, and a significant main effect of Modality on ΔCNS, with a large effect size. Increases in INS and CNS ratings were significantly greater for *Transitional* compared to *Neutral*, and for *Multisensory* compared to *Audiovisual*.

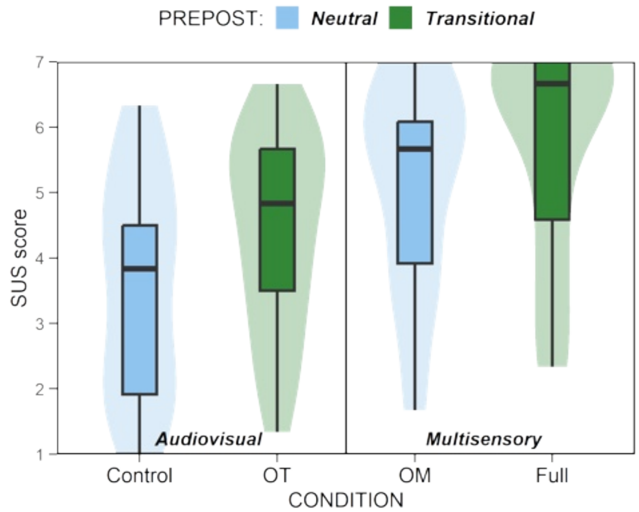
Overall, no significant interaction effects emerged between PrePost and Modality for any dependent variable.

5.2 Impact Ratings of Specific Design Features

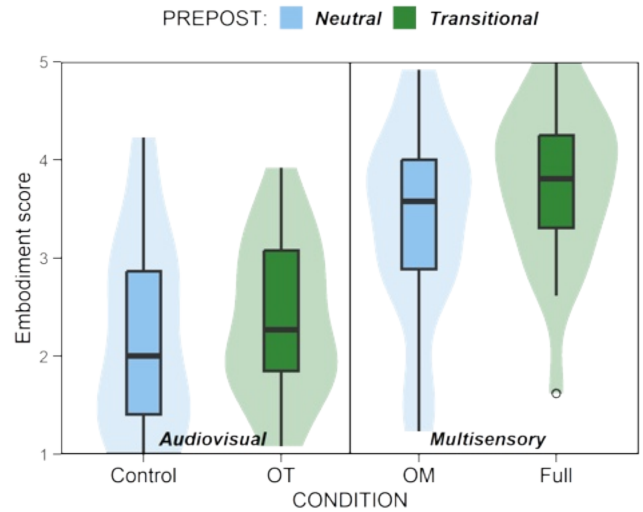
To address RQ3, participants rated the perceived impact of specific design features on their overall experience. Ratings are shown in Figure 8, grouped by transitional, multisensory, and overarching elements. Within each group, features are ordered by mean impact, highlighting those with the strongest positive effects. We also computed impact scores across all individual features for the multisensory and transitional categories. A paired t-test revealed that overall, multisensory impact ratings ($M = 2.76, SD = .95$) were significantly higher than transitional impact ratings ($M = 1.20, SD = .93$) with a large effect size ($t(19) = 6.57, p < .001$, $d_z = 1.47$).

5.3 Effects on Nature Connectedness One Week Post Study

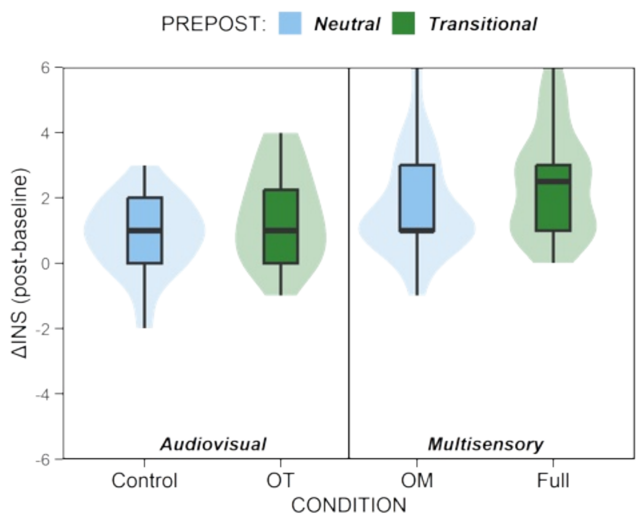
Regarding RQ4, we investigated whether the overall VR intervention impacted participants' state NC one week after the study (see Table 6 and Figure 9). While the descriptive data suggest



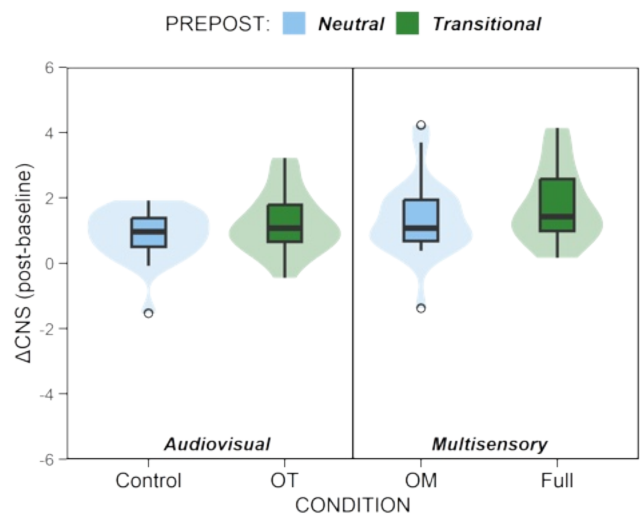
(a) Sense of Presence



(b) Level of Embodiment



(c) Change in INS



(d) Change in CNS

Figure 6: Condition comparison of post-condition outcomes. (a) Sense of presence (possible range: 1 to 7) and (b) embodiment (possible range: 1 to 5). (c) Inclusion of Nature in Self (ΔINS) and (d) Connectedness to Nature Scale (ΔCNS) changes (possible range: -6 to 6). Box plots (showing the median, quartiles, and potential outliers) are overlaid on violin plots, which illustrate the underlying data distribution via kernel density estimates. All main effects are significant, see Table 5. OT = *Only Transitional*, OM = *Only Multisensory*.

a slight decrease in INS ratings at follow-up compared to baseline, the Wilcoxon signed-rank test revealed no significant difference between $INS_{baseline}$ and $INS_{follow\text{-}up}$. For CNS ratings, the paired t-test showed a significant difference between $CNS_{baseline}$ and $CNS_{follow\text{-}up}$, with a medium effect size, demonstrating an increase in CNS scores from baseline to follow-up.

5.4 Qualitative Interview Results

This subsection presents our thematic analysis on the interview data, primarily addressing how PrePost and Modality influenced presence, embodiment, and NC (RQ1, RQ2). Results also offer insights into the impact of specific design features (RQ3). Our analysis produced 37 final codes (printed in bold) within six main themes, which structure this section. We begin with participants' overall condition preferences, followed by key insights.

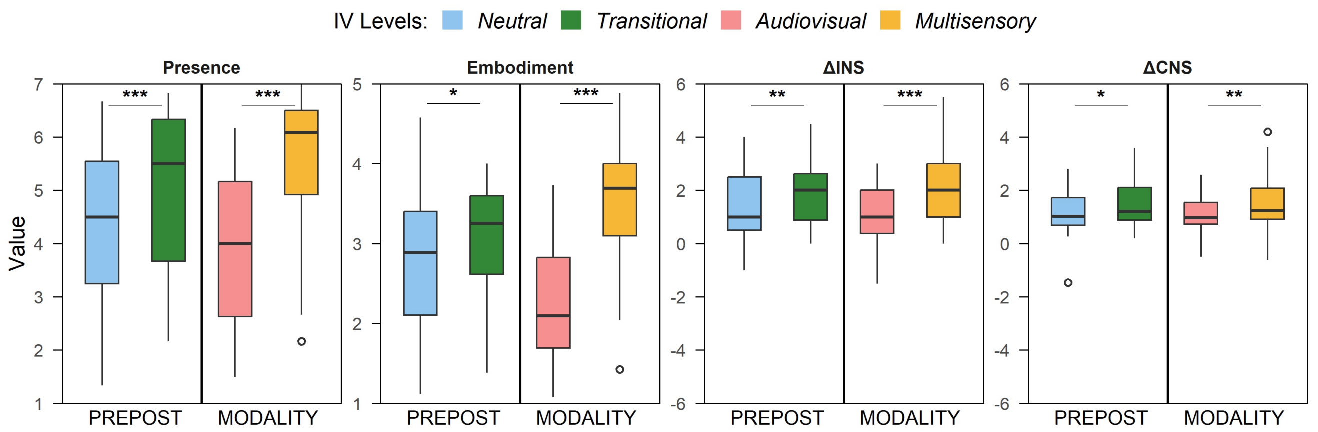


Figure 7: Boxplots showing the post-condition outcomes for each level of the independent variables, PrePost (Neutral, Transitional) and Modality (Audiovisual, Multisensory), on presence, embodiment, ΔINS, and ΔCNS. Boxplots display medians, quartiles, and potential outliers. Asterisks indicate significant main effects (*p < .05, **p < .01, ***p < .001), see Table 5.

5.4.1 Overall Condition Preferences. Most participants ($N = 13$; P1-6, P9-10, P13, P15-16, P18-19) found the *Full* condition (with Transitional and Multisensory features) most impactful, with some highlighting its completeness, immersive quality, and combination of sensory input with reflective elements. A few (P7, P11-12) identified the *Only Transitional* condition as most impactful, for example, highlighting the actor's performance and the darker lighting (P12). Participants who found the *Only Multisensory* condition most impactful (P8, P17, P20) mainly attributed this to it being the first version they encountered (P8, P17). One participant chose the *Control* condition, explaining it allowed them to think more about the *"connectedness aspect"* (P14).

When asked which version they liked and enjoyed most, the vast majority ($N = 17$; P1–10, P12–13, P15–19) again chose the *Full* condition. One participant (P11) most enjoyed the *Only Transitional* and two participants (P14, P20) the *Only Multisensory* condition, which they experienced third. P14 added that the second Multisensory exposure helped them notice more sensory details. Nobody said the *Control* condition was the version they liked most.

5.4.2 Impact of Transitions on Presence. In the first theme, the interviews showed that the transitional pre- and post-VR experience positively influenced participants' sense of presence before, during, and after VR, supporting our quantitative findings. Many participants (P3–4, P7–8, P10, P16–20) reported a **smooth transition and readiness for VR**, facilitated by the transitional setting. For example, P17 explained that *"seeing the plants and the lights (...) felt more natural to enter the VR experience,"* making them feel *"more ready"* and *"more prepared"*. Several (P4-5, P10, P14, P17-18) also described a **sense of stepping into another world prior to VR**. P4 shared, *"once you passed through this barrier [curtain], you kind of entered (...) a different world, and you could fully, fully embrace the situation,"* while P10 said they already felt disconnected from reality before putting on the headset, to the extent that after entering VR, they *"didn't notice it, that [they] had a VR headset on."* In the transitional room, a **sense of being in nature** was reported by many (P1–2, P4–5, P8, P12, P16, P18), with P5 describing a feeling of *"being in a forest or some nature place."* A few (P2, P7, P13) noted **spiritual or meditative connotations**, such as P13's description of *"entering a meditation room."* The transitional setting also helped **establish atmosphere and environmental coherence** (P3, P10–14), setting the mood for what was to come. Participants appreciated the alignment between the physical space and the VR narrative and setting. Others (P1, P3–6, P20) described a sense of **heightened presence, focus and engagement prior to VR**, due to factors like dim lighting, the actor's performance, and entering a separate room section. These positive effects appeared to carry over into the VR experience itself, with several (P4–5, P10, P13, P16, P19) reporting a **heightened sense of presence in VR** facilitated by the transitional pre-VR experience. Here, P19 stated that it allowed them to *"get into the scene more quickly"* and *"take it all in more from the get-go, (...) more fully experience it."* Finally, a few (P4, P17, P19) described a **smoother transition back to reality** post-VR, supported by darker lighting and natural elements. P4 described a gradual return to reality during the mirror phase and the exit from the transitional room back to the neutral area, whereas P15 and P18 reported an **abrupt transition back to reality**, with P15 noting the mirror's disconnecting and reflection-inducing effect as the most impactful element.

5.4.3 Impact of Transitions on Embodiment. The pre- and post-VR transitions also shaped participants' sense of embodiment as a tree. Several (P1, P4–5, P7–8) described the transitional pre-VR setting as **priming and facilitating embodiment**, with the actor's performance (P7-8), nature decoration (P1, P5), dim lighting (P1), and sense of stepping into another world when changing rooms (P4) making them feel like, *"I will become a tree soon. It felt like I am really transitioning"* (P8). Post-VR, seeing themselves in the mirror after HMD removal often triggered a **shift from tree to human self** (P1–2, P5, P7, P16), with P16 sharing that in VR they saw their body as a tree body, but seeing themselves in the mirror after VR reminded them they were human again. Similarly, some (P4,

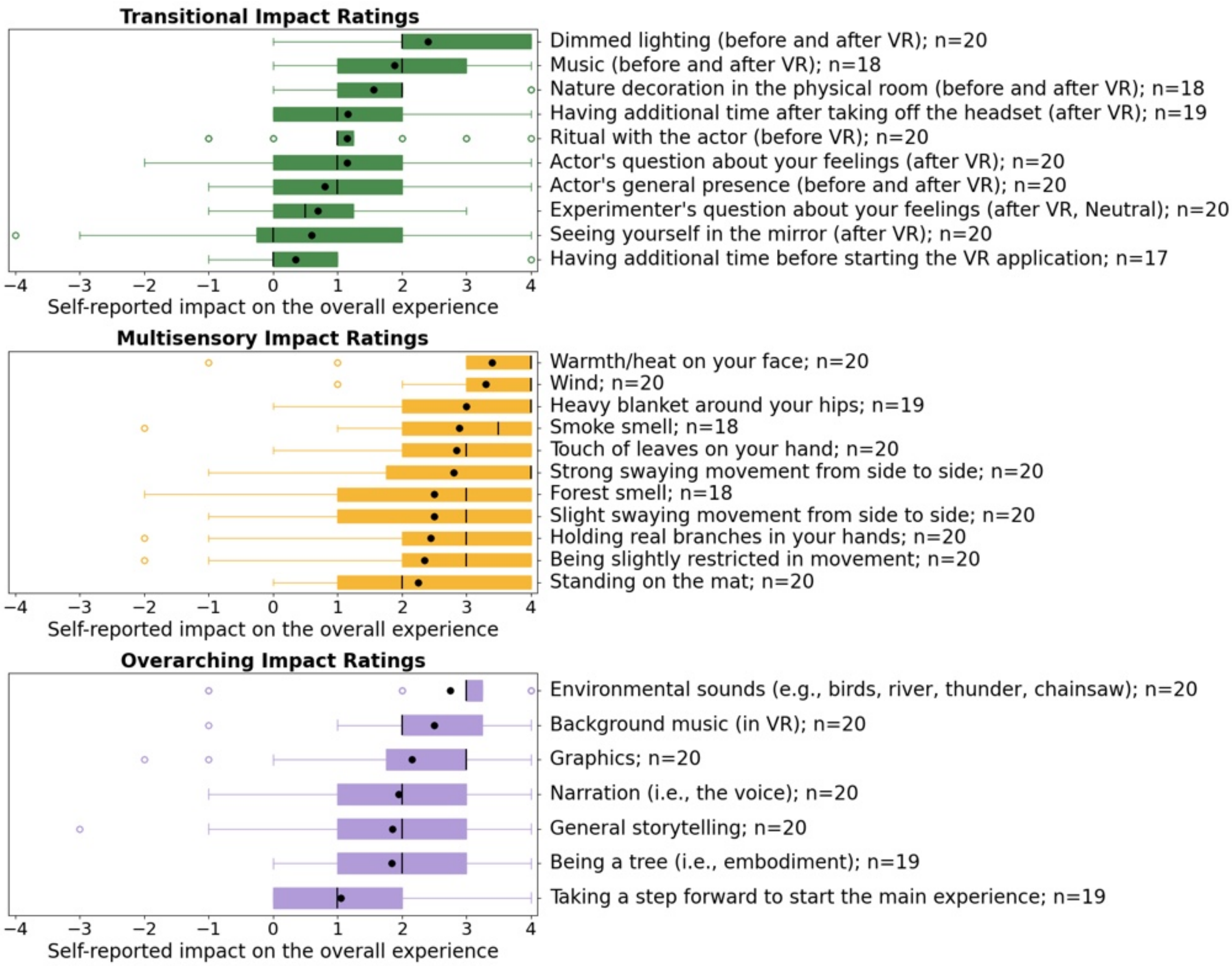
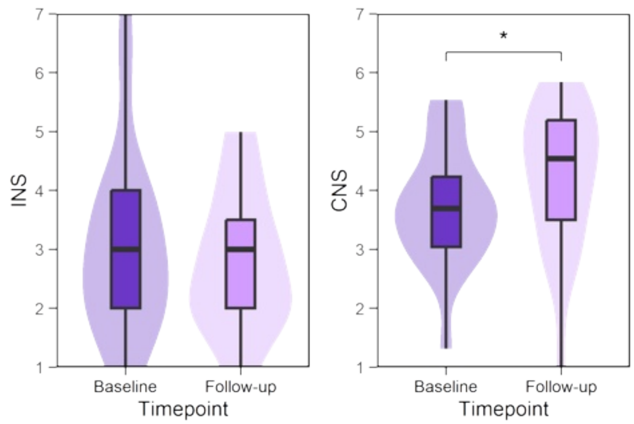


Figure 8: Participant-reported impact ratings for specific design features, reported on the following scale: -4: Very strong negative impact, -3: Strong negative impact, -2: Moderate negative impact, -1: Slight negative impact, 0: No impact (Neutral), 1: Slight positive impact, 2: Moderate positive impact, 3: Strong positive impact, 4: Very strong positive impact. Box plots show medians (black vertical lines), means (black circles), interquartile ranges (shaded boxes), and outliers (outlined circles). The features are sorted by their means for each section. If $n \neq 20$, some participants answered "× Did not notice".

Table 6: Descriptive statistics, Shapiro-Wilk normality tests, and paired t-tests or Wilcoxon signed-rank tests examining NC effects between baseline and one-week follow-up questionnaire responses. For effect sizes, Cohen's d_z or rank-biserial correlation r are reported. Significant effects at $\alpha = 0.05$ are bolded.

	Baseline			Follow-up			Normality		Paired t-test			Wilcoxon		
	M	SD	Mdn	M	SD	Mdn	W	p	t	p	d_z	V	p	r
INS	3.05	1.54	3.00	2.79	1.18	3.00	.90	**.002**				47.50	.510	-.22
CNS	3.72	1.03	3.69	4.20	1.25	4.54	.96	.269	-2.26	**.037**	.52			

Note: M = Mean, SD = Standard Deviation, Mdn = Median, INS = Inclusion of Nature in Self, CNS = Connectedness to Nature



(a) INS **(b) CNS**

Figure 9: Baseline and follow-up results for NC, including (a) Inclusion of Nature in Self (INS) and (b) Connectedness to Nature Scale (CNS) scores (possible ranges: 1 to 7). Box plots (showing the median, quartiles, and potential outliers) are overlaid on violin plots, which illustrate the underlying data distribution via kernel density estimates. We found a significant increase in CNS, but not INS.

P7, P17) noted a **tree–human body symmetry**, seeing parallels between the virtual tree body (in front of them in the last virtual scene) and their human body in the mirror, which for P4 and P17 prolonged their identification with the tree body beyond VR. For several (P4, P6, P11, P17–18), the mirror prompted **body identity confusion and reflection**, with P18 initially failing to recognise their own face in the mirror due to being deeply immersed in the story, not expecting to see a human being. P11 described feeling *"sad for myself, not just the tree"* during the mirror phase, noting difficulty distinguishing whether the sympathy was for the tree, for themselves as the tree, or for themselves, blurring the line between 'self' (human) and 'other' (tree).

5.4.4 Impact of Transitions on Nature Connectedness. When specifically asked whether the transitional pre- and post-VR experience affected how connected they felt to nature, half (P2, P3, P4-5, P8, P10, P12, P15-18) affirmed a positive impact, while many (P1, P4, P6-7, P11, P13-14, P19) felt unaffected, and two (P9, P20) gave no clear answer. Several (P1-2, P8, P10, P16-17) described that the **biophilic design** (natural elements, plants, and ivy decoration) enhanced their NC, with P2 feeling *"a little bit more connected to nature"* when surrounded by plants. Pre-VR, a few (P5, P8, P14) attributed increased NC to the **actor's poetry**, which included references to nature. P8 noted this fostered empathy and feeling connected to nature earlier than in the *Neutral* conditions.

The post-VR experience provided an opportunity for reflection. Several (P3, P7, P10, P15, P20) described **mirror reflections on the experience**, appreciating time to *"think about what I just experienced"* (P15) and to *"organise my thoughts"* (P7). Many (P1, P4, P8, P10, P15, P17, P20) went deeper, engaging in **mirror reflections on nature connectedness and responsibility**. For example, P10 felt the mirror *"really gave me more reflection on what this means to the real world (...), reflecting on also my own actions about the environment."* Moreover, P1 expressed a sense of responsibility for environmental protection enhanced by the mirror: *"When I saw myself in the mirror, it just reflected too much embarrassment in me, because being human, I'm also responsible for every dos and don'ts, so I think that all just connected"* and *"this is us who do it, nobody else."* Apart from reflective processes, a few (P5, P17, P20) also experienced **mirror-associated empathy** towards nature (P5, P17) or the tree (P20). In contrast, statements from a few participants (P2, P14, P19) suggested a **mirror/actor interference** post-VR, reporting discomfort with the mirror (e.g., P14 disliked *"looking in the mirror recently"*) or a desire for solitude after VR (P2, P19). This may have limited opportunities for reflection and, indirectly, reduced NC.

5.4.5 Impact of Multisensory Enhancements on Presence. Participants widely reported that multisensory enhancements heightened their sense of presence during VR. Many (P4, P9, P11–13, P16–17, P19) described feeling like a **passive observer in audiovisual conditions**, like watching a movie, when multisensory stimuli were not present. Regarding *Multisensory* conditions, almost all participants (P2–4, P6–19) expressed an **enhanced sense of being there** in the virtual environment, with P13 calling it *"the most important part of making me feel like I was actually there."* P19 described how *"the combination of the smells, the touches, the temperature changes, the wind"* helped them forget the underlying technology and just be *"there in the moment, experiencing it."* In this context, haptics and smells were both frequently reported. Participants mentioned various tactile and some kinesthetic sensations that contributed to a haptics-induced sense of being there (P2-4, P8-9, P11, P14, P16-19): stepping onto the mat (P2, P4, P16-17), touch of leaves on their hand (P9, P16, P18), heat (P11, P16, P19), swaying movement (P8-9, P16), and weighted blanket (P14). Many (P3–4, P7, P13, P16, P18–19) also reported a smell-induced sense of being there from the forest smell during the calm nature scene and the smoke smell during nature destruction. P18 shared, *"the destruction scene went from being something that I was observing to being something that (...) was happening around me, and I was in the environment"* due to the added smell. Most (P2–3, P6–11, P13, P16–20) also reported **enhanced realism**, contributing this mostly to haptics: heat (P7–11, P16, P18, P20), direct touch and movement (P9, P11, P16, P19–20), wind (P6, P8); and to smells (P2-3, P6, P13). For instance, P10 noted, *"the fire really got real"* with the heat, and P3 said, *"the smell created the feeling in me that it's actually happening."* Multisensory input also led to **enhanced immersion** in several participants (P7, P10, P14, P17, P19–20), which refers to the system's technical capabilities [65].

Moreover, some participants (P1, P3, P9, P15, P18, P20) described **presence-induced sensory errors**, such as feeling wind in moments were it was not physically present (P1, P3, P9, P15, P20), stating that this illusory wind contributed to their sense of being there (P3, P9), or believing the real smell was imagined (P18), indicating strong sensory integration. Nevertheless, many (P6–7, P11, P14, P16, P18–19) also reported **distraction or breaks in presence** when multisensory stimuli briefly took attention away from the story, caused by technical curiosity (P6, P7, P14), loss of stable footing (P6, P11, P18), or sensory mismatches (P14, P16, P19).

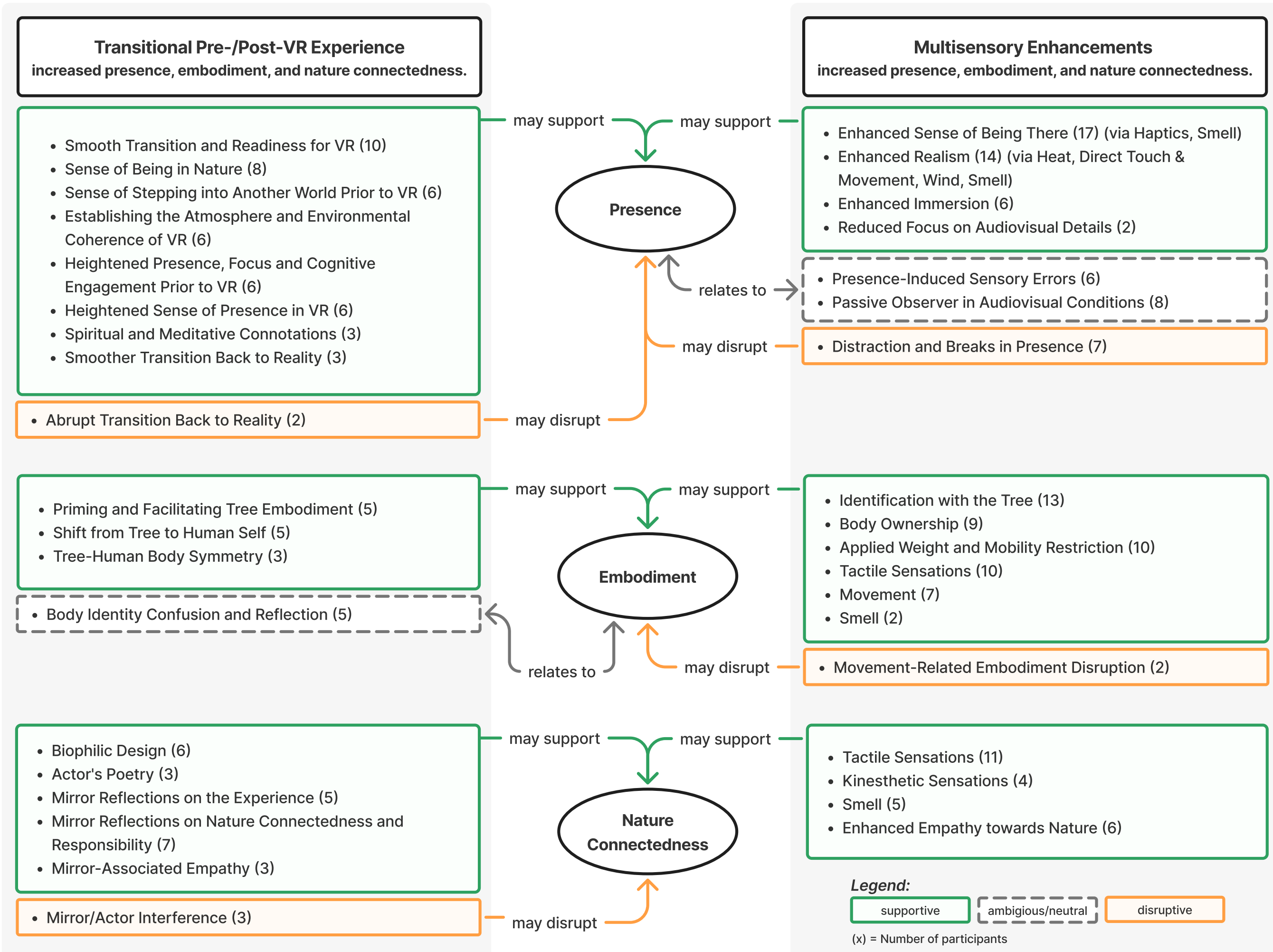


Figure 10: Summary of qualitative insights from interviews on how the independent variables (transitional pre- and post-VR experience, multisensory enhancements) influenced presence, embodiment and nature connectedness.

Although such breaks are generally undesirable, two participants suggested a potential benefit of slight distraction: **reduced focus on audiovisual details** (P7, P10) in *Multisensory* conditions, with P10 noting that *"some flaws [in graphics] could definitely be made up for with more sensations."*

5.4.6 Impact of Multisensory Enhancements on Embodiment. Multisensory enhancements strongly shaped participants' sense of embodying the tree. Most (P1, P3-11, P15, P17-18) reported **identification with the tree**, with P8 describing *"you really feel like you're the one who's burning, and you're the tree (...) who is really ruined"* (P8). P4 reflected on the combined effect of the additional weight, smells, being rocked around, and holding real branches, with which, *"I really became the tree, kind of. I embraced being a tree."* Many (P1, P5, P10, P12-13, P15, P17, P19-20) described a sense of **body ownership** over (parts of) the tree body, for example, supported by tactile cues, mobility restriction, and swaying movement. P12 noted, *"I really liked the idea of swaying, it really felt that I am a part of the tree."*

Next, we will identify the types of stimuli that contributed to participants' sense of embodiment. Half of participants (P3-6, P9-10, P12, P17, P19-20) emphasised **applied weight and mobility restriction** as especially effective. The weighted blanket around participants' hips made them feel restricted in their movements (P3-5, P9-10, P12, P17, P19), *"heavy"* (P3-5), *"grounded"* (P4, P6), and *"connected to the roots"* (P9), helping them feel like a tree. The first time the weighted blanket went on, P19 felt like, *"oh, I just became the tree."* Similarly, half (P1-2, P4-5, P7, P9, P11, P15, P17-18) highlighted **tactile sensations** as supporting embodiment: leaves touching the hand (P2, P5, P11, P15), holding branches (P1, P4, P7, P17), and heat (P9, P18). Many (P4-5, P7, P12-13, P15, P20) also expressed that **movement** helped them embody the tree, especially the swaying movement applied to the participants, with P15 sharing, *"swaying back and forth (...) I felt like I was actually a tree, in like a split second of pulling."* However, two (P2, P18) experienced

movement-related embodiment disruption when the motion felt inconsistent with being a tree, for example, when P18 had to adjust their stance. Finally, two participants (P4, P8) described **smell** as reinforcing embodiment, with P8 using first-person framing (*"smelling myself"*) when referring to the pine scent.

5.4.7 Impact of Multisensory Enhancements on Nature Connectedness. Almost all participants (P1, P3–10, P12–13, P15–20) reported that multisensory features enhanced their NC. The most frequently mentioned stimuli enhancing their connection were **tactile sensations** (P2–3, P5, P7, P9–11, P16–18, P20), including heat (P5, P11, P16, P18), holding branches (P7, P10, P20), leaves touching the hand (P9, P11, P20), stepping on the mat (P2, P17), and wind (P3, P9). For instance, P20 noted, *"this brush of leaves reminded me that I'm closer to nature."* A few also highlighted **kinesthetic sensations** (P2, P5, P9, P17), such as the restrictive weight of the blanket (P17) which P5 interpreted as a *"metaphoric symbol (...) for the responsibility of the human"*, or the swaying (P2, P9). When being swayed from side to side, P9 was *"able to connect to the other trees, like other trees were also swaying."* Several (P3, P5, P7, P13, P16) also reported that **smell** helped them feel connected to nature, especially the pine/forest scent in the calm nature scene (P7, P13). Moreover, for P5, the combination of senses seemed to have evoked a complete overlap between self and nature: *"But with this experience, for example, with the touch, smell, and heat on my face, I felt like I am the nature. I don't come from the nature. I am the nature."*

Facilitated by the multisensory stimuli, many (P4–5, P8–9, P16, P18) also described **enhanced empathy towards nature**, directed towards trees (P4, P16, P18), plants and birds (P4), or nature in general (P5, P16). For example, P18 explained, *"after feeling like a tree, then yeah, I wouldn't want trees to get hurt."* Additionally, P5, who described themselves as selfish and usually not empathic, reported a profound emotional impact, feeling as if they were the one on fire and unable to escape during the experience, sharing, *"If you can just affect me as a person who never [has] empathy, maybe it's useful for everyone."*

6 Discussion

In a mixed-methods approach, we investigated how pre- and post-VR transitions and multisensory stimuli during VR influenced participants' sense of presence, embodiment, and NC in a tree-embodiment experience. Structured around our research questions, we now discuss our quantitative and qualitative findings in relation to prior work, outline design recommendations, and conclude with limitations and directions for future research.

Overall, framed within the transformational framework for VR experiences [75, 76], our results demonstrate that both transitional and multisensory design factors supported a 'cognitive shift' in participants, manifested as a significantly higher increase in NC in *Transitional* and *Multisensory* conditions. This finding contributes to the limited body of research on the potential of VR-based nature embodiment to promote NC [1, 39, 68, 70]. It contradicts previous findings from Spangenberger et al. [68], who found no benefit of multisensory stimuli during tree embodiment, and extends prior work by proposing real-world transitions as a novel design technique that significantly enhanced nature embodiment. As such, our study serves as an extension of prior research on embodying natural entities and, specifically, trees in VR. In this context, prior work [68–70] has typically used the same fixed "Tree" VR application (see Section 2.3). Our study extends this line of research by introducing an alternative, customisable VR application that also affords tree embodiment, thereby offering higher flexibility for experimental adaptation and strengthening the generalisability of findings within nature embodiment research.

Importantly, we found no significant interaction effects across any dependent variable, which means that pre-/post-VR transitions and multisensory enhancements operated independently. This suggests that designers can flexibly employ either element to enhance outcomes, while combining them may offer cumulative but not interdependent benefits.

6.1 RQ1: Pre- and Post-VR Transitions Increase Presence, Embodiment, and Nature Connectedness

Our findings indicate that pre- and post-VR transitions significantly enhanced participants' sense of presence, embodiment, and NC.

Presence ratings were significantly higher when the experience included transitional pre- and post-VR phases as opposed to neutral entries and exits, which is in line with prior work on gradual transitions enhancing presence via virtual transitional environments [29, 74, 80]. This study may be the first to offer quantitative evidence supporting the presence-boosting effect of real-world transitional elements, building upon preliminary qualitative findings from Kitson et al. [34] regarding the importance of designing 'set and setting' before and after VR sessions. Qualitative analysis further supports our results. Many participants indicated that the pre-VR experience played a key role in fostering presence. Most notably, the pre-VR setting led to a smoother transition into VR, more openness and readiness for VR, and heightened focus and presence prior to VR, which also carried over into VR, resulting in enhanced presence during the VR experience. Moreover, the transitional pre-VR design established the atmosphere and environmental coherence of the virtual environment, supporting recommendations in prior work on designing for continuity between real and virtual world for the best user experience [5, 34].

Design recommendation. Enhance presence by attending to users' pre-VR state of mind. Creating a calming and engaging entry space that users walk into, using suitable lighting, sound, and decoration coherent with the virtual world, can support mental readiness and a smoother transition into VR.

The pre- and post-VR transitions also significantly enhanced embodiment, which was somewhat supported by our thematic analysis, showing that the transitional pre-VR setting, including the actor's ritual and nature decoration, primed the tree embodiment, helping participants to transition into the tree body. To our knowledge, this is the first study to examine the pre- and post-VR setting in the context of nature embodiment, which may indicate the potential of coherent storytelling and foreshadowing design elements in the physical space in increasing readiness to take on an alternative body. Furthermore, seeing their reflection in a mirror after VR helped participants transition back to their human selves. At the same time, the tree-human body symmetry evoked by the mirror resulted in a prolonged identification with the tree body in some participants, extending into the post-VR phase, even beyond VR.

Design recommendation. Enhance nature embodiment with pre-VR rituals and foreshadowing elements, preparing users for the transition. Post-VR cues, such as mirrors, can aid in re-grounding users in their human body.

The transitions significantly enhanced participants' NC, which was reinforced by the qualitative responses, with several participants noting that the nature-focused decoration in the pre- and post-VR setting contributed to their heightened connection to nature, aligning with the expected positive effects of biophilic design [27, 30] and foreshadowing elements [34]. The interviews also revealed strong evidence that seeing themselves in the mirror during the post-VR experience offered a powerful moment for reflection. This prompted many participants to contemplate their connection to nature, humanity's responsibility in environmental protection, and, in some cases, their own environmental actions. As suggested in Benford et al.'s trajectories framework [5], our transitional post-VR ending successfully supported reflection and discussion with the actor. This aligns with prior work showing that pairing a 360° VR tree-perspective experience with a post-VR reflection activity elicited empathic reflections [24]. Nevertheless, a few participants found the mirror or the actor's presence distracting or disruptive, highlighting the subjective nature of post-VR reflection and pointing to opportunities to explore alternative social settings.

Design recommendation. Enhance nature connectedness by incorporating biophilic design in the physical setting and providing opportunities for post-VR reflection, for example, through mirrors and guided conversations, while allowing some flexibility for different user preferences.

To our knowledge, these findings contribute the first empirical evidence that transitional pre- and post-VR settings may provide measurable benefits in fostering NC and embodiment, and the first statistical evidence in supporting presence, thereby extending prior findings from a qualitative case study [34].

6.2 RQ2: Multisensory Enhancements Increase Presence, Embodiment, and Nature Connectedness

Similarly, our results suggest that multisensory stimuli, encompassing carefully selected haptic and olfactory cues that match the environment and narrative, significantly enhanced participants' sense of presence, embodiment, and NC. These results diverge from Spangenberger et al. [68], who recently did not find benefits of multisensory enhancements on presence or NC during tree embodiment in VR. We speculate this discrepancy may be due to a higher variety and dynamics in our haptic stimuli. Our design included various types of haptic enhancements that were not present in Spangenberger et al. [68], including thermoception, aerodynamics, standing on a textured mat, touch of leaves, holding tree branches instead of controllers, kinesthetic swaying motion, and weight (large, weighted blanket around participants' hips and legs vs. small ankle weights in [68]). In particular, the infrared heat used in our study was rated as overall most impactful by our participants, while Spangenberger et al. [68] did not incorporate thermoception. Moreover, while Spangenberger et al. incorporated stable tactile props worn by the participants, which did not seem to change throughout the experience, our more dynamic stimuli (i.e., swaying motion becoming stronger and more hostile over time; heat and wind added only during the intense destruction scene; and weighted blanket removed in the exact moment the tree embodiment stopped) may have contributed to our observed benefits.

The sense of presence was significantly higher in *Multisensory* conditions compared to *Audiovisual* conditions, consistent with most prior VR research [43]. Participants described a stronger sense of "being there" and greater realism, to which both haptic and olfactory stimuli contributed. Interviews revealed that heat in particular enhanced perceived realism (in line with previous work [26, 81]), while especially olfactory and tactile stimuli (e.g., stepping onto the textured mat, feeling leaves touch their hands) further reinforced the sense of being there in the forest, in line with prior studies [43]. At the same time, the additional sensory stimuli occasionally introduced short moments of distraction in several participants, which may have caused brief breaks in presence [63], drawing attention away from the virtual world. This may reflect the increased cognitive load that can come with multisensory input [19], as well as the potential for haptic feedback to be experienced as disturbing [79]. While our design aimed for close synchrony between multisensory cues and the virtual scene (e.g., heat coinciding with the fire; touch of leaves in sync with visual leaves), it remains possible that some of the reported distractions were related to subtle mismatches, as incongruent or mistimed stimuli are known to disrupt presence and embodiment [7, 60].

Design recommendation. Enhance presence with synchronous multisensory stimuli (especially olfactory, tactile, and thermal cues), while avoiding overstimulation or sensory mismatches that may risk distraction.

Regarding embodiment of the tree, our findings indicate that participants not only mentally adopted the perspective of a tree, as observed in prior work by Spangenberger et al. [69], but many reported that they truly *"became the tree"* when multisensory stimuli were present. Our quantitative and qualitative data suggest that multisensory enhancements had the strongest impact on embodiment, aligning with research on the role of visual-tactile stimulation in supporting virtual body ownership [17, 20]. In *Multisensory* conditions, participants described a strong sense of body ownership over (parts of) the tree, feeling as if they were *"actually a tree"* (P15) and, in several cases, a profound identification with the tree. Types of stimuli most often cited as impactful were: (i) weighted blanket, which applied weight and restricted mobility; (ii) tactile sensations, particularly touch of leaves, holding branches, and heat, and (iii) the side-to-side swaying motion, which was perceived as the tree moving in the wind. Together, these dynamic haptic cues enabled participants not only to imagine but to physically experience being a tree. In summary, both tactile and kinesthetic haptics emerged as central to fostering nature embodiment, while olfactory cues played a minor role.

Design recommendation. Enhance nature embodiment with a combination of tactile and kinesthetic haptics, enabling sensations of texture, weight, posture, and movement associated with the embodied entity.

Multisensory enhancements also led to significantly stronger increases in NC, which we expected based on prior work linking presence, embodiment, and NC [1, 68]. Several participants reported enhanced empathy towards trees and nature, indicating emotional depth added through sensory engagement. One participant expressed a complete overlap in their 'inclusion of nature in self': *"(...) with the touch, smell, and heat on my face, I felt like I am the nature. I don't come from the nature. I am the nature."* (P5). This aligns with questionnaire responses, which showed a significantly higher increase in INS scores when multisensory enhancements were present. In contrast to Spangenberger et al. [68], who found no additional NC benefits from tactile and olfactory enhancements during tree embodiment, our qualitative findings suggest that tactile sensations were especially effective in enhancing NC, in particular heat, touch of leaves, and holding branches, which are elements not incorporated in Spangenberger et al.'s study.

Design recommendation. Enhance nature connectedness with nature-themed tactile sensations and thermoception.

6.3 RQ3: Impact of Specific Design Features

This study also investigated the impact of specific design features in both the *Transitional* and *Multisensory* conditions, building on prior research on nature embodiment (see Section 2.3). All individual design features (grouped by transitional, multisensory, and overarching) were rated positively by participants, though their perceived impact varied in strength. Among the transitional pre- and post-VR features, dimmed lighting, background music, and nature decoration were rated as most impactful. These elements require relatively little effort, though they depend on a physical setting, making them particularly suited to in-person studies, museum installations or educational contexts, rather than standalone consumer VR applications. The effects of the actor's presence and the post-VR mirror with reflective questioning were less clear: while interviews revealed that these elements often triggered meaningful reflection, in line with prior recommendations [5], some participants experienced discomfort, which likely contributed to the variability in impact ratings of these features. As actor-based elements require extensive preparation and limit scalability, their benefits may not always justify the resources, though they may be more feasible in long-term museum or art installations. Therefore, future user studies could build upon our design and explore self-directed or AI-supported reflective spaces during the post-VR phase.

Multisensory features were overall rated as more impactful than transitional ones. Descriptive data showed heat and wind as the highest-rated stimuli, reinforcing interview reports of their role in enhancing presence and NC, consistent with prior evidence that thermal and aerodynamic cues increase presence [26, 81]. As heat lamps can be easily automated, as in this study, thermal stimulation offers a low-effort, high-impact design choice for VR. Wind, while salient, was less frequently remembered in interviews, suggesting its influence may be subtle. While manually applied airflow allowed precise and dynamic control, it also limits scalability, which is why future work could instead employ automated fans [26]. Other haptic (weighted blanket, leaves, branches, mat) and olfactory stimuli (forest, smoke) were also positively rated, with the weighted blanket most often highlighted in interviews for supporting tree embodiment, which supports and extends prior work that relied on subtler ankle weights [68].

Finally, regarding the overarching VR application, auditory design (i.e., in-VR environmental sounds, music, and narration) received the highest impact ratings, surpassing graphics and tree embodiment. This aligns with a recent review emphasising the power of audio to influence affective, cognitive, and motivational outcomes in VR [6].

Design recommendations. (1) For pre- and post-VR transitions, prioritise accessible, low-effort elements such as lighting, music, and appropriate decoration in the physical environment, and provide opportunities for post-VR reflection. (2) During VR, enhance the embodied nature experience with thermal, aerodynamic, and weight stimulation, employing automated delivery (e.g., heat lamps, fans) to increase scalability and reduce experimental effort. (3) Leverage in-VR sound design as a high-impact and scalable means of supporting embodied VR experiences.

6.4 RQ4: Sustained Emotional Bonds to Nature One Week Post Study

Our results may indicate that the overall VR intervention led to sustained positive effects on CNS. While INS scores (reflecting the cognitive dimension of NC [56]) returned to baseline levels at follow-up one week after the study, scores on the multi-item CNS scale (reflecting the affective-experiential dimension of NC [41]) were significantly higher at follow-up compared to baseline, which may suggest a sustained *emotional* bond to nature. Similar to our findings, Ahn et al. [1] found that coral embodiment in VR briefly increased INS compared to video (approaching significance), but this effect further weakened one week later. Their results mirror the pattern we observed on the INS scale, overall suggesting that VR's influence on the cognitive dimension of NC might be short-lived, while extending prior work by showing for the first time that virtual nature embodiment may produce increases in affective-experiential NC (CNS) that last for at least one week. Moreover, this echoes findings from a meta-analysis showing that VR experiences tend to enhance emotional, but not cognitive empathy towards others [40].

6.5 Limitations & Future Work

While our study offers novel insights into transitional and multisensory design in VR for NC, some limitations exist that should be acknowledged. The interactive and human-led nature of parts of the experience may have introduced slight variability across conditions, and the physical setup limits scalability. Although participants varied in prior VR experience and concern for environmental problems, the sample consisted primarily of students living in Germany; caution is therefore warranted when generalising to broader populations. Condition order may have influenced participants' experiences and preferences, though counterbalancing was used to reduce this effect. In a few cases, minor technical problems due to HMD connectivity issues in the dimly lit room caused short delays during the pre-VR experience. Due to the exploratory nature of this study, individual differences such as trait CNS were not controlled for in our analysis and may have introduced confounding effects, which should be addressed in future work. Furthermore, due to our within-subject design, it was not possible to compare the one-week follow-up data across the four conditions. Therefore, it remains unclear whether the sustained positive effects on emotional NC were attributable to the transitional or multisensory designs, or to the overall study experience. In future work, longer-term effects could be examined in a between-subjects design. Moreover, the experience occasionally elicited strong emotional reactions, underscoring both the transformative potential of the design and the importance of sensitive facilitation.

While outside the scope of this paper, several promising directions emerge. Future studies could evaluate lower-effort, scalable alternatives, such as video or avatar-based guidance replacing the live actor and more automated delivery of multisensory cues. To further advance the transitional experience, future designs may include XR passthrough as an additional transition phase, richer biophilic design with dynamic nature projections, or even situating the experience in real-world natural settings. Beyond NC, future research should examine whether *I Am a Tree* fosters pro-environmental behaviours, the final stage of the transformational framework [75, 76], ideally through repeated exposure and long-term follow-ups. Complementing self-report with behavioural, implicit, or physiological measures could provide a richer understanding of its impact. In addition, personalisation may further enhance the experience, for example, by combining physiological sensing with AI-driven adaptation to adjust stimulus intensity to users' stress levels. Finally, extending embodiment to other natural entities and environments (e.g., urban green spaces, glaciers, or oceans) could test the broader applicability of our transitional and multisensory design. Furthermore, we speculate that our findings may have relevance beyond virtual nature embodiment. The design recommendations around pre- and post-VR transitions, as well as the targeted use of multisensory stimuli, may also inform broader HCI domains concerned with embodied or emotionally-engaging experiences, not limited to VR. In particular, the potential benefits of mentally preparing users for an embodied experience, designing the physical setting, and promoting reflection afterwards may extend beyond environmental applications and VR design, offering promising directions for future HCI research on multisensory and holistic interaction design.

7 Conclusion

In this work, we investigated the impact of transitional design elements before and after VR and multisensory stimuli during a VR tree experience. We developed *I Am a Tree*, a transformative VR experience that enables users to embody a tree and witness environmental destruction from nature's perspective. Through a mixed-methods approach ($N = 20$), we showed that transitional pre- and post-VR experiences and multisensory enhancements both significantly increased presence, embodiment, and nature connectedness, extending prior research on VR-based nature embodiment. To our knowledge, this is the first study on nature embodiment to integrate (i) transitional pre- and post-VR elements, (ii) a diverse range of multisensory stimuli, and (iii) in-depth qualitative interviews, providing a more comprehensive understanding of participants' subjective experiences. Our findings further indicate that lighting, music, and biophilic design emerged as particularly impactful in the pre- and post-VR setting, while heat, wind, and weight stimuli seemed to be the most influential multisensory stimuli. Moreover, affective-experiential nature connectedness was still elevated one week later, which may suggest sustained emotional effects of the overall study experience. Future work can build on our findings using a between-subject design to identify which elements of the design may contribute to these lasting effects on connectedness.

Together, our findings highlight the potential value of a holistic approach to VR design that considers users' state of mind and real-world experiences before, during, and after VR; an aspect largely underexplored in VR and HCI research. We offer novel insights on how designers and HCI researchers can maximise presence, embodiment, and nature connectedness in nature-focused VR experiences, as well as more broadly in holistic experience design. We showed that VR's highly immersive and perspective-taking capabilities offer compelling opportunities for creating transformative experiences that can guide users towards a more connected and sustainable relationship with nature.

Looking ahead, future work should examine longer-term behavioural outcomes and explore how the experience can be scaled and adapted for broader use in environmental education, public engagement, and climate communication. Additionally, the demonstrated value of transitional and multisensory elements may inform the design of transformative VR experiences beyond the nature domain, with relevance for empathy-building, museum installations, immersive storytelling, and other contexts where emotional and embodied engagement are essential.

Open Science & Aids

We encourage readers to reproduce and extend our results and analysis. Therefore, our experimental setup, collected data, and analysis scripts are openly available on the Open Science Framework: https://osf.io/at6xz/. During the preparation of this work, the authors used OpenAI's GPT-5 and Grammarly for grammar and style editing. All content was reviewed and edited by the authors, who take full responsibility for the final publication.

Author Contributions

Lisa L. Townsend: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Julian Rasch:** Conceptualization, Formal Analysis, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing; **Amy Grech:** Conceptualization, Investigation, Methodology, Writing – review & editing; **Bernhard E. Riecke:** Conceptualization, Methodology, Resources, Supervision, Writing – review & editing; **Sven Mayer:** Conceptualization, Formal Analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

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References

[1] Sun Joo Ahn, Joshua Bostick, Elise Ogle, Kristine L Nowak, Kara T McGillicuddy, and Jeremy N Bailenson. 2016. Experiencing nature: Embodying animals in immersive virtual environments increases inclusion of nature in self and involvement with nature. *Journal of Computer-Mediated Communication* 21, 6 (2016), 399–419. doi:10.1111/jcc4.12173

[2] Sun Joo Grace Ahn, Jeremy N Bailenson, and Dooyeon Park. 2014. Short-and long-term effects of embodied experiences in immersive virtual environments on environmental locus of control and behavior. *Computers in Human Behavior* 39 (2014), 235–245. doi:10.1016/j.chb.2014.07.025

[3] Gladys Barragan-jason, Claire de Mazancourt, Camille Parmesan, Michael Christopher Singer, and Michel Loreau. 2021. Human–nature connectedness as a pathway to sustainability: A global meta-analysis. *Conservation Letters* 15 (2021), 1–7. doi:10.1111/conl.12852

[4] Lisa L. Barth, Fariba Mostajeran, Frank Steinicke, Bernhard E. Riecke, and Simone Kühn. 2025. Immersive videos of natural and urban environments can enhance awe and psychological well-being. *Frontiers in Virtual Reality* 6 (2025), 1532991. doi:10.3389/frvir.2025.1532991

[5] Steve Benford, Gabriella Giannachi, Boriana Koleva, and Tom Rodden. 2009. From interaction to trajectories: designing coherent journeys through user experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI '09)*. Association for Computing Machinery, New York, NY, USA, 709–718. doi:10.1145/1518701.1518812

[6] Isak de Villiers Bosman, Oğuz 'Oz' Buruk, Kristine Jørgensen, and Juho Hamari. 2024. The effect of audio on the experience in virtual reality: a scoping review. *Behaviour & Information Technology* 43, 1 (2024), 165–199. doi:10.1080/0144929X.2022.2158371

[7] Matthew Botvinick and Jonathan Cohen. 1998. Rubber hands 'feel'touch that eyes see. *Nature* 391, 6669 (1998), 756–756. doi:10.1038/35784

[8] James V Bradley. 1958. Complete counterbalancing of immediate sequential effects in a Latin square design. *J. Amer. Statist. Assoc.* 53, 282 (1958), 525–528. doi:10.2307/2281872

[9] Elena Brambilla, Evi Petersen, Karen Stendal, Vibeke Sundling, Tadhg E MacIntyre, and Giovanna Calogiuri. 2024. Effects of immersive virtual nature on nature connectedness: A systematic review and meta-analysis. *Digital Health* 10 (2024), 20552076241234639. doi:10.1177/20552076241234639

[10] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101. doi:10.1191/1478088706qp063oa

[11] Colin A Capaldi, Raelyne L Dopko, and John M Zelenski. 2014. The relationship between nature connectedness and happiness: A meta-analysis. *Frontiers in Psychology* 5 (2014), 15 pages. doi:10.3389/fpsyg.2014.00976

[12] Zikun Chen, Roshan Lalintha Peiris, and Kouta Minamizawa. 2017. A Thermally Enhanced Weather Checking System in VR. In *Adjunct Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology* (Québec City, QC, Canada) *(UIST '17 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 123–125. doi:10.1145/3131785.3131825

[13] Alice Chirico, Pietro Cipresso, David B Yaden, Federica Biassoni, Giuseppe Riva, and Andrea Gaggioli. 2017. Effectiveness of immersive videos in inducing awe: an experimental study. *Scientific reports* 7, 1 (2017), 1218. doi:10.1038/s41598-017-01242-0

[14] Alice Chirico, Francesco Ferrise, Lorenzo Cordella, and Andrea Gaggioli. 2018. Designing awe in virtual reality: An experimental study. *Frontiers in psychology* 8 (2018), 2351. doi:10.3389/fpsyg.2017.02351

[15] Alice Chirico, Marta Pizzolante, Alexandra Kitson, Elena Gianotti, Bernhard E. Riecke, and Andrea Gaggioli. 2022. Defining Transformative Experiences: A Conceptual Analysis. *Frontiers in psychology* 13 (2022), 790300. doi:10.3389/fpsyg.2022.790300

[16] Alice Chirico, Giulia Wally Scurati, Chiara Maffi, Siyuan Huang, Serena Graziosi, Francesco Ferrise, and Andrea Gaggioli. 2021. Designing virtual environments for attitudes and behavioral change in plastic consumption: A comparison between concrete and numerical information. *Virtual Reality* 25 (2021), 107–121. doi:10.1007/s10055-020-00442-w

[17] Woong Choi, Liang Li, Satoru Satoh, and Kozaburo Hachimura. 2016. Multisensory integration in the virtual hand illusion with active movement. *BioMed research international* 2016, 1 (2016), 1–9. doi:10.1155/2016/8163098

[18] Jacob Cohen. 2013. *Statistical Power Analysis for the Behavioral Sciences* (2 ed.). Academic Press: New York, NY, USA, New York, USA. doi:10.4324/9780203771587

[19] Paulo G. de Barros and Robert W. Lindeman. 2013. Performance effects of multi-sensory displays in virtual teleoperation environments. In *Proceedings of the 1st Symposium on Spatial User Interaction* (Los Angeles, California, USA) *(SUI '13)*. Association for Computing Machinery, New York, NY, USA, 41–48. doi:10.1145/2491367.2491371

[20] Mie C. S. Egeberg, Stine L. R. Lind, Sule Serubugo, Denisa Skantarova, and Martin Kraus. 2016. Extending the human body in virtual reality: effect of sensory feedback on agency and ownership of virtual wings. In *Proceedings of the 2016 Virtual Reality International Conference* (Laval, France) *(VRIC '16)*. Association for Computing Machinery, New York, NY, USA, Article 30, 4 pages. doi:10.1145/2927929.2927940

[21] Liisalotte Elme, Maria LM Jørgensen, Gert Dandanell, Aske Mottelson, and Guido Makransky. 2022. Immersive virtual reality in STEM: is IVR an effective learning medium and does adding self-explanation after a lesson improve learning outcomes? *Educational technology research and development* 70, 5 (2022), 1601–1626. doi:10.1007/s11423-022-10139-3

[22] Andrea Gaggioli. 2016. Transformative Experience Design. In *Human Computer Confluence Transforming Human Experience Through Symbiotic Technologies*, Andrea Gaggioli, Alois Ferscha, Giuseppe Riva, Stephen Dunne, and Isabelle Viaud-Delmon (Eds.). De Gruyter, Berlin, 97–121. doi:10.1515/9783110471137-006

[23] Liuna Geng, Jingke Xu, Lijuan Ye, Wenjun Zhou, and Kexin Zhou. 2015. Connections with nature and environmental behaviors. *PloS one* 10, 5 (2015), e0127247. doi:10.1371/journal.pone.0127247

[24] Amy Grech, Lisa L Barth, Julian Rasch, Bernhard E Riecke, Ross Brisco, Andrew Wodehouse, et al. 2025. More Than a Feeling: Empathic Reflection Through Virtual Experiences. In *DS 137: Proceedings of the International Conference on Engineering and Product Design Education (E&PDE 2025)*. The Design Society, Glasgow, United Kingdom, 301–306. doi:10.35199/EPDE.2025.51

[25] Marcus Hedblom, Bengt Gunnarsson, Behzad Iravani, Igor Knez, Martin Schaefer, Pontus Thorsson, and Johan N Lundström. 2019. Reduction of physiological stress by urban green space in a multisensory virtual experiment. *Scientific reports* 9, 1 (2019), 10113. doi:10.1038/s41598-019-46099-7

[26] Felix Hülsmann, Julia Fröhlich, Nikita Mattar, and Ipke Wachsmuth. 2014. Wind and warmth in virtual reality: implementation and evaluation. In *Proceedings of the 2014 Virtual Reality International Conference* (Laval, France) *(VRIC '14)*. Association for Computing Machinery, New York, NY, USA, Article 24, 8 pages. doi:10.1145/2617841.2620712

[27] Shih-Han Hung and Chun-Yen Chang. 2021. Health benefits of evidence-based biophilic-designed environments: A review. *Journal of People, Plants, and Environment* 24, 1 (2021), 1–16. doi:10.11628/ksppe.2021.24.1.1

[28] Christopher D Ives, Matteo Giusti, Joern Fischer, David J Abson, Kathleen Klaniecki, Christian Dorninger, Josefine Laudan, Stephan Barthel, Paivi Abernethy, Berta Martín-López, et al. 2017. Human–nature connection: a multidisciplinary review. *Current opinion in environmental sustainability* 26 (2017), 106–113. doi:10.1016/j.cosust.2017.05.005

[29] Sungchul Jung, Pamela J Wisniewski, and Charles E Hughes. 2018. In limbo: The effect of gradual visual transition between real and virtual on virtual body ownership illusion and presence. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, New York, NY, USA, 267–272. doi:10.1109/VR.2018.8447562

[30] Stephen R Kellert, Judith Heerwagen, and Martin Mador. 2008. *Biophilic design: the theory, science and practice of bringing buildings to life*. John Wiley & Sons, Inc., Hoboken, NJ. https://www.wiley.com/en-us/Biophilic+Design-p-9780470163344

[31] Behrang Keshavarz and Heiko Hecht. 2011. Validating an efficient method to quantify motion sickness. *Human factors* 53, 4 (2011), 415–426. doi:10.1177/0018720811403736

[32] Jai Khanna, Anne Seo-young Lee, and Saleh Kalantari. 2025. The mediating role of technology affordances in virtual reality perspective-taking: a systematic literature review. *Virtual Reality* 29, 1 (2025), 66. doi:10.1007/s10055-024-01095-9

[33] Alexandra Kitson, Mirjana Prpa, and Bernhard E. Riecke. 2018. Immersive Interactive Technologies for Positive Change: A Scoping Review and Design Considerations. *Frontiers in psychology* 9 (2018), 1354. doi:10.3389/fpsyg.2018.01354

[34] Alexandra Kitson, Ekaterina R. Stepanova, Ivan A. Aguilar, Natasha Wainwright, and Bernhard E. Riecke. 2020. Designing Mind(set) and Setting for Profound Emotional Experiences in Virtual Reality. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference (ACM Digital Library)*, Ron Wakkary (Ed.). Association for Computing Machinery, New York,NY,United States, 655–668. doi:10.1145/3357236.3395560

[35] Jarrod Knibbe, Jonas Schjerlund, Mathias Petraeus, and Kasper Hornbæk. 2018. The Dream is Collapsing: The Experience of Exiting VR. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3173574.3174057

[36] Mark See Teck Lee, Kit Ling Chin, Paik San H'ng, Manohar Mariapan, Swee Yaw Ooi, Seca Gandaseca, and Mariusz Maminski. 2023. The role of forest and environmental conservation film in creating nature connectedness and pro-environmental behaviour. *Quarterly Review of Film and Video* 40, 2 (2023), 187–214. doi:10.1080/10509208.2021.1996310

[37] Xin Liu. 2017. *Inward to Outward*. Master's thesis. Massachusetts Institute of Technology, Cambridge, MA. https://dspace.mit.edu/handle/1721.1/114069

[38] Lara Maister, Mel Slater, Maria V. Sanchez-Vives, and Manos Tsakiris. 2015. Changing bodies changes minds: owning another body affects social cognition. *Trends in cognitive sciences* 19, 1 (2015), 6–12. doi:10.1016/j.tics.2014.11.001

[39] David M Markowitz, Rob Laha, Brian P Perone, Roy D Pea, and Jeremy N Bailenson. 2018. Immersive virtual reality field trips facilitate learning about climate change. *Frontiers in psychology* 9 (2018), 2364. doi:10.3389/fpsyg.2018.02364

[40] Alison Jane Martingano, Fernanda Hererra, and Sara Konrath. 2021. Virtual reality improves emotional but not cognitive empathy: A meta-analysis. *Technology, Mind, and Behavior* 2, 1 (2021), 7–21. doi:10.1037/tmb0000034

[41] F Stephan Mayer and Cynthia McPherson Frantz. 2004. The connectedness to nature scale: A measure of individuals' feeling in community with nature. *Journal of environmental psychology* 24, 4 (2004), 503–515. doi:10.1016/j.jenvp.2004.10.001

[42] F Stephan Mayer, Cynthia McPherson Frantz, Emma Bruehlman-Senecal, and Kyffin Dolliver. 2009. Why is nature beneficial? The role of connectedness to nature. *Environment and behavior* 41, 5 (2009), 607–643. doi:10.1177/0013916508319745

[43] Miguel Melo, Guilherme Gonçalves, Pedro Monteiro, Hugo Coelho, José Vasconcelos-Raposo, and Maximino Bessa. 2020. Do multisensory stimuli benefit the virtual reality experience? A systematic review. *IEEE transactions on visualization and computer graphics* 28, 2 (2020), 1428–1442. doi:10.1109/TVCG.2020.3010088

[44] Aske Mottelson, Andreea Muresan, Kasper Hornbæk, and Guido Makransky. 2023. A S1 - 4ystematic Review and Meta-analysis of the Effectiveness of Body Ownership Illusions in Virtual Reality. *ACM Transactions on Computer-Human Interaction (TOCHI)* 30, 5 (2023), 1–42. doi:10.1145/3590767

[45] Benson G Munyan, Sandra M Neer, Deborah C Beidel, and Florian Jentsch. 2016. Olfactory stimuli increase presence during simulated exposure. In *Virtual, Augmented and Mixed Reality: 8th International Conference (VAMR 2016)*. Springer, Toronto, Canada, 164–172. doi:10.1007/978-3-319-39907-2_16

[46] Elizabeth K Nisbet, John M Zelenski, and Steven A Murphy. 2009. The nature relatedness scale: Linking individuals' connection with nature to environmental concern and behavior. *Environment and behavior* 41, 5 (2009), 715–740. doi:10.1177/001391650831874

[47] Akimi Oyanagi and Ren Ohmura. 2019. Transformation to a bird: overcoming the height of fear by inducing the proteus effect of the bird avatar. In *Proceedings of the 2nd International Conference on Image and Graphics Processing* (Singapore, Singapore) *(ICIGP '19)*. Association for Computing Machinery, New York, NY, USA, 145–149. doi:10.1145/3313950.3313976

[48] Timothy Patterson and Insook Han. 2019. Learning to teach with virtual reality: Lessons from one elementary teacher. *TechTrends* 63, 4 (2019), 463–469. doi:10.1007/s11528-019-00401-6

[49] Daniel Pimentel and Sri Kalyanaraman. 2022. The effects of embodying wildlife in virtual reality on conservation behaviors. *Scientific Reports* 12, 1 (2022), 6439. doi:10.1038/s41598-022-10268-y

[50] Alison Pritchard, Miles Richardson, David Sheffield, and Kirsten McEwan. 2020. The relationship between nature connectedness and eudaimonic well-being: A meta-analysis. *Journal of happiness studies* 21 (2020), 1145–1167. doi:10.1007/s10902-019-00118-6

[51] Denise Quesnel and Bernhard E Riecke. 2018. Are you awed yet? How virtual reality gives us awe and goose bumps. *Frontiers in psychology* 9 (2018), 2158. doi:10.3389/fpsyg.2018.02158

[52] Beatrice Rammstedt and Oliver P John. 2007. Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. *Journal of research in Personality* 41, 1 (2007), 203–212. doi:10.1016/j.jrp.2006.02.001

[53] Giuseppe Riva. 2022. Virtual Reality. In *The Palgrave Encyclopedia of the Possible*, Vlad Petre Glăveanu (Ed.). Springer International Publishing, Cham, 1740–1750. doi:10.1007/978-3-030-90913-0_34

[54] Roly Russell, Anne D Guerry, Patricia Balvanera, Rachelle K Gould, Xavier Basurto, Kai MA Chan, Sarah Klain, Jordan Levine, and Jordan Tam. 2013. Humans and nature: How knowing and experiencing nature affect well-being. *Annual review of environment and resources* 38, 1 (2013), 473–502. doi:10.1146/annurev-environ-012312-110838

[55] Morgan Faith Schebella, Delene Weber, Lisa Schultz, and Philip Weinstein. 2020. The nature of reality: Human stress recovery during exposure to biodiverse, multisensory virtual environments. *International Journal of Environmental Research and Public Health* 17, 1 (2020), 56. doi:10.3390/ijerph17010056

[56] P. Wesley Schultz. 2001. The structure of environmental concern: Concern for self, other people, and the biosphere. *Journal of environmental psychology* 21, 4 (2001), 327–339. doi:10.1006/jevp.2001.0227

[57] P. Wesley Schultz. 2002. Inclusion with Nature: The Psychology Of Human-Nature Relations. In *Psychology of Sustainable Development*, Peter Schmuck and Wesley P. Schultz (Eds.). Springer US, Boston, MA, 61–78. doi:10.1007/978-1-4615-0995-0_4

[58] P Wesley Schultz, Chris Shriver, Jennifer J Tabanico, and Azar M Khazian. 2004. Implicit connections with nature. *Journal of environmental psychology* 24, 1 (2004), 31–42. doi:10.1016/S0272-4944(03)00022-7

[59] Valentine Seymour. 2016. The Human—Nature Relationship and Its Impact on Health: A Critical Review. *Frontiers in Public Health* 4 (2016), 260. doi:10.3389/fpubh.2016.00260

[60] Mel Slater. 2009. Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences* 364, 1535 (2009), 3549–3557. doi:10.1098/rstb.2009.0138

[61] Mel Slater and Maria V. Sanchez-Vives. 2016. Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI* 3 (2016), 74. doi:10.3389/frobt.2016.00074

[62] Mel Slater, Bernhard Spanlang, and David Corominas. 2010. Simulating virtual environments within virtual environments as the basis for a psychophysics of presence. *ACM transactions on graphics (TOG)* 29, 4 (2010), 1–9. doi:10.1145/1833349.1778829

[63] Mel Slater and Anthony Steed. 2000. A virtual presence counter. *Presence* 9, 5 (2000), 413–434. doi:10.1162/105474600566925

[64] Mel Slater, Martin Usoh, and Anthony Steed. 1994. Depth of presence in immersive virtual environments. *Presence: Teleoperators and Virtual Environments* 3 (1994), 130. doi:10.1162/pres.1994.3.2.130

[65] Mel Slater and Sylvia Wilbur. 1997. A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments* 6, 6 (1997), 603–616. doi:10.1162/pres.1997.6.6.603

[66] Masashi Soga and Kevin J Gaston. 2016. Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment* 14, 2 (2016), 94–101. doi:10.1002/fee.1225

[67] Monica Soliman, Johanna Peetz, and Mariya Davydenko. 2017. The impact of immersive technology on nature relatedness and pro-environmental behavior. *Journal of Media Psychology* 29 (2017), 8–17. doi:10.1027/1864-1105/a000213

[68] Pia Spangenberger, Sarah-Christin Freytag, and Sonja M Geiger. 2024. Embodying nature in immersive virtual reality: Are multisensory stimuli vital to affect nature connectedness and pro-environmental behaviour? *Computers & Education* 212 (2024), 104964. doi:10.1016/j.compedu.2023.104964

[69] Pia Spangenberger, Sonja Maria Geiger, and Sarah-Christin Freytag. 2022. Becoming nature: Effects of embodying a tree in immersive virtual reality on nature relatedness. *Scientific Reports* 12, 1 (2022), 1311. doi:10.1038/s41598-022-05184-0

[70] Pia Spangenberger, Jule M Krüger, Sonja M Geiger, Georg Felix Reuth, Lena Baumann, and Steve Nebel. 2025. Compassion is key: How virtually embodying nature increases connectedness to nature. *Journal of Environmental Psychology* 102 (2025), 102521. doi:10.1016/j.jenvp.2025.102521

[71] Pia Spangenberger, N Matthes, F Kapp, L Kruse, and JL Plass. 2025. Orchestrating iVR technology in an authentic classroom setting and its effects on factual knowledge, comprehension and transfer. *Educational technology research and development* 73, 1 (2025), 387–413. doi:10.1007/s11423-024-10409-2

[72] Giuseppina Spano, Annalisa Theodorou, Gerhard Reese, Giuseppe Carrus, Giovanni Sanesi, and Angelo Panno. 2023. Virtual nature, psychological and psychophysiological outcomes: A systematic review. *Journal of Environmental Psychology* 89 (2023), 102044. doi:10.1016/j.jenvp.2023.102044

[73] Anthony Steed, Steve Benford, Nick Dalton, Chris Greenhalgh, Ian MacColl, Cliff Randell, and Holger Schnädelbach. 2002. Mixed-reality interfaces to immersive projection systems. In *Proceedings of the Immersive Projection Technology Workshop*. IEEE Computer Society, Orlando, Florida, USA. http://www.cs.bris.ac.uk/Publications/pub_info.jsp?id=2000011

[74] Frank Steinicke, Gerd Bruder, Klaus Hinrichs, Anthony Steed, and Alexander L Gerlach. 2009. Does a gradual transition to the virtual world increase presence?. In *2009 IEEE Virtual Reality Conference*. IEEE, New York, NY, USA, 203–210. doi:10.1109/VR.2009.4811024

[75] Ekaterina R. Stepanova, Denise Quesnel, Alexandra Kitson, Mirjana Prpa, and Bernhard E. Riecke. 2017. Virtual Reality as a Tool for Inducing and Understanding Transformative Experiences. Psychonomic Society 58th Annual Meeting, Vancouver, BC, Canada. https://www.researchgate.net/publication/320757424_Virtual_Reality_as_a_Tool_for_Inducing_and_Understanding_Transformative_Experiences [Poster].

[76] Ekaterina R. Stepanova, Denise Quesnel, and Bernhard Riecke. 2018. Transformative Experiences Become More Accessible Through Virtual Reality. In *2018 IEEE Workshop on Augmented and Virtual Realities for Good (VAR4Good)*. IEEE, Reutlingen, Germany, 1–3. doi:10.1109/VAR4GOOD.2018.8576881

[77] Ekaterina R. Stepanova, Denise Quesnel, and Bernhard E. Riecke. 2019. Understanding AWE: Can a Virtual Journey, Inspired by the Overview Effect, Lead to an Increased Sense of Interconnectedness? *Frontiers in Digital Humanities* 6 (2019), 9. doi:10.3389/fdigh.2019.00009

[78] Edmund R Thompson. 2007. Development and validation of an internationally reliable short-form of the positive and negative affect schedule (PANAS). *Journal of cross-cultural psychology* 38, 2 (2007), 227–242. doi:10.1177/0022022106297301

[79] Luca Turchet, Paolo Burelli, and Stefania Serafin. 2012. Haptic feedback for enhancing realism of walking simulations. *IEEE transactions on haptics* 6, 1 (2012), 35–45. doi:10.1109/TOH.2012.51

[80] Dimitar Valkov and Steffen Flagge. 2017. Smooth immersion: The benefits of making the transition to virtual environments a continuous process. In *Proceedings of the 5th Symposium on Spatial User Interaction*. ACM, Brighton, United Kingdom, 12–19. doi:10.1145/3131277.3132183

[81] Joseph Wareing, Glyn Lawson, Che Abdullah, and Tessa Roper. 2018. User perception of heat source location for a multisensory fire training simulation. In *2018 10th Computer Science and Electronic Engineering (CEEC)*. IEEE, New York, NY, USA, 214–218. doi:10.1109/CEEC.2018.8674211

[82] Jacob O. Wobbrock, Leah Findlater, Darren Gergle, and James J. Higgins. 2011. The aligned rank transform for nonparametric factorial analyses using only anova

procedures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 143–146. doi:10.1145/1978942.1978963

[83] Andrea Stevenson Won, Jeremy Bailenson, Jimmy Lee, and Jaron Lanier. 2015. Homuncular flexibility in virtual reality. *Journal of Computer-Mediated Communication* 20, 3 (2015), 241–259. doi:10.1111/jcc4.12107

[84] Ziwen Ye, Jiali Huang, and Wen Wen. 2025. Research on the interaction design of VR plant installation under the perspective of embodiment. In *Conference Proceedings of DiGRA 2025: Games at the Crossroads*. Digital Games Research Association, Tampere, Finland. https://dl.digra.org/index.php/dl/article/view/2688

[85] Nicola L Yeo, Mathew P White, Ian Alcock, Ruth Garside, Sarah G Dean, Alexander J Smalley, and Birgitta Gatersleben. 2020. What is the best way of delivering virtual nature for improving mood? An experimental comparison of high definition TV, 360 video, and computer generated virtual reality. *Journal of environmental psychology* 72 (2020), 101500. doi:10.1016/j.jenvp.2020.101500