Embodiment in Nature: How Avatar Choice Shapes an Underwater Virtual Reality Experience

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***Abstract*—Immersive Virtual Reality (IVR) applications are increasingly used to foster environmental awareness and promote pro-environmental behaviors by reducing psychological distance and enhancing nature-connectedness. In this study, we investigated how different avatars, in an underwater educational IVR experience, influence users' Sense of Embodiment (SoE), measured through self-reported and physiological measures (Electrodermal Activity – EDA). Results showed that the Sense of Agency plays a key role in enhancing overall SoE, raising it when users embody an avatar capable of free movement and interaction. Conversely, restricted interactivity resulted in higher EDA, suggesting that this may be due to the frustration caused by the unmet desire to move and explore.**

***Index Terms*—Immersive Virtual Reality, Embodiment, Physiological Measures, Climate Change, Human-Computer Interaction**

I. Introduction

Although climate change is a global problem, which implies a growing need for global political commitment and structural measures to address it [11], the factors that effectively motivate individuals to adopt pro-environmental behavior remain unclear. In recent decades, factors such as rapid population growth and increasing demand for resources have negatively impacted our planet and environment. However, the consequences of these phenomena are not immediately visible and do not affect people's daily lives [5], making raising awareness about climate change challenging.

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When it comes to the adoption of sustainable behaviors, the literature reports how rational intentions do not always translate into concrete actions [19]. Thus, while strategies based solely on cognitive aspects (i.e., providing information on climate change) may not be sufficient to generate behavioral change [26], the literature emphasizes the role of *Nature Connectedness*–an emotional and experiential bond with nature–in promoting pro-environmental actions by integrating cognitive processes with affective stimuli [4]. Additionally, previous literature [14, 25] has shown that the perception of climate change can be influenced by four types of *Psychological Distance*: *temporal* (how far in the future an event is), *spatial* (physical distance), *social* (how connected one feels to those affected), and *hypothetical* (how likely the event seems). The effects of climate change are particularly influenced by temporal and spatial distance [24], as the consequences of human actions are not immediately visible and often occur far from the sources of anthropogenic pollution.

Among new technologies, Immersive Virtual Reality (IVR) is regarded as a promising tool to reduce *Psychological Distance* and foster this emotional bond [2, 5]. In addition to providing first-person experiences, this technology offers the ability to embody inhabitants of the affected environments and visualize habitat changes that have occurred over time, making otherwise invisible phenomena, such as the evolution of ocean acidification or coral reef bleaching, visible [2, 6]. It also elicits intense affective and cognitive processes, necessary to raise awareness about climate change [20]. These processes are reinforced when the Sense of Embodiment (SoE)–the subjective perception of the virtual body as one's own–occurs [12]. In this regard, a suitable strategy to gain a deeper understanding of the SoE experienced by users is combining subjective self-reported measures with physiological data (such as Electrodermal Activity - EDA), uncovering both explicit and implicit processes.

II. State of the Art

Virtual Reality allows users to adopt a first-person perspective, embody a virtual body that replaces the real one, have control over it, and perceive it as their own [12]. This body replacement generates perceptual modulations and behavioral responses that affect the quality of the interaction between the user and the Virtual Environment (VE) [10], ultimately known as SoE.

One of the major contributions to the SoE conceptualization was provided by Kilteni et al. [12], who outlined its structure in terms of three main components: Sense of Agency (SoA), Sense of Self Location (SoSL), and Sense of Body Ownership (SoBO). The SoA refers to the perception of being the author of one's own actions and is closely related to the correspondence between the sensory expectations generated by the motor command and the feedback received [7]. The quality of agency depends largely on the synchronization between the user's motor inputs and the virtual avatar's responses [21]. The SoSL represents the spatial experience of feeling located within a body and is defined as "a particular volume in space in which one feels localized" [12]. Finally, the SoBO refers to the feeling that the virtual body is an integral part of the self and is perceived as the source of one's sensations [12].

Originally, the phenomenon was studied in relation to the neural plasticity of the human mind, which allows it to accept an external body as part of its own, through the famous Rubber Hand Illusion [3], in which participants perceived a fake rubber hand as their own. In recent years, innovative new applications of the phenomenon have emerged in the field of environmental awareness, particularly on climate change, leading to the creation of IVR simulations that allow participants to experience first-hand experiences from the perspective of other living things, including animals or non-sentient entities such as plants or corals [23]. In particular Ahn et al. [1] were among the first to implement an immersive experience that allowed users to embody themselves in a coral and directly observe the effects of ocean acidification on their virtual bodies. As a further example, Ponto et al. [17] developed a VE in which users embodied themselves in an Adelia penguin, experiencing first-hand its life cycle, resulting in an increased level of empathy toward the animal and a significant correlation between embodiment and empathy. Moreover, the experience also fostered informal learning, highlighting the educational potential of these simulations in strengthening connection with nature and pro-environmental engagement. Finally, Boffi et al. [2] created an IVR experience in which users could embody a coral, a hermit crab, or a turtle and witness the degradation of a coral reef over sixty years due to climate change, with preliminary findings indicating high user engagement and promising results about self-reported SoE.

Given the multifaceted nature of the SoE and its central role in reducing the *Psychological Distance* and fostering emotional engagement, there is a growing need for studies that assess the experienced SoE resulting from different virtual body designs and affordances, to inform the development of more effective IVR experiences for environmental education. In this regard, SoE can be measured in different ways: self-reported questionnaires remain the most commonly used approach in the literature, as they are non-invasive and directly capture participants' conscious experiences [8, 22]. However, these measures are not always reliable, as they are based on users' subjective perceptions. To address this limitation, objective measures–such as proprioceptive drift, physiological responses, and neurophysiological recordings–are also widely used. In particular, a recent review by Guy et al. [10] identified a range of physiological measures that can be used to assess embodiment in IVR, such as EDA, heart rate, and electroencephalography (EEG). Therefore, to gain a more comprehensive understanding of what happens when users embody a virtual avatar during an IVR experience, combining subjective and objective methods would be beneficial [10], thereby integrating conscious self-perceptions with underlying implicit processes and avoiding potential biases related to self-reported measures.

III. Materials and Methods

This study aims to investigate which character elicits a higher level of embodiment in the *Envisioning Corals* application. In a previous study [2], we investigated the general SoE provided by the application without analyzing avatar-specific differences and relying exclusively on self-reported measures. In contrast, the present work integrates both self-reported and physiological data, combining a questionnaire with EDA recordings, to identify the most suitable avatar for future studies assessing the educational effectiveness of the application, and to explore the relationship between subjective embodiment and physiological activation.

A. Envisioning Corals

Envisioning Corals is an educational IVR application that allows users to impersonate different coral reef inhabitants. By embodying one of three distinct species–a coral, a hermit crab, or a sea turtle–users experience the marine environment from different ecological perspectives, fostering emotional engagement and a deeper connection with nature. We designed the application on the basis of the framework by Scurati et al. [18], which outlines three design dimensions for IVR experiences on environmental topics: emotional, rational, and practical. Our design primarily focuses on the emotional dimension, using embodiment to elicit empathy for the chosen species. Educational content supports the rational dimension, while the practical aspect is addressed through messages encouraging environmentally responsible behavior.

Fig. 1: Food collected by the characters during the experience: microorganisms moved by the sea current (coral – left), small debris (hermit crab – middle), and jellyfish (turtle – right).

Users begin the experience by selecting one of the three avatars [Fig. 1]. The *Coral* allows users to impersonate a static animal. While they cannot move through the environment, they are able to interact with it by moving their ”hands” to capture floating microorganisms carried by sea currents for nourishment. The *Hermit Crab* allows users to explore the seabed in search for organic debris to eat, while the *Sea Turtle* enables users to swim through the reef, searching for jellyfish as nourishment.

Given that the consequences of anthropogenic pollution are not immediately visible, but may occur in long time intervals, the VE, inspired by Maldivian coral reefs, has been designed to evolve over a simulated 60-year period, from 1960 to 2020. Initially vibrant and rich in biodiversity, it deteriorates over time due to environmental pollution: colors fade to a white tone, marine life declines, and waste accumulates. These changes, deliberately exaggerated, reflect the growing environmental impact and affect gameplay by reducing food availability, making survival increasingly difficult. To further reinforce this aspect, a simple UI displays the avatar's health status and the passage of time.

To make this experience not only emotional but also informative, two narrated audio segments provide educational context. The first one introduces the selected species characteristics, its diet, and the game mechanics, while the second one explains the observed environmental changes and their causes. Then, some practical advices on how to reduce our environmental impact are introduced. To provide users with a positive message and to avoid leaving them with a sense of powerlessness, during this final audio the reef is restored to its original splendor, visually reinforcing the idea that proactive environmental actions can lead to positive changes.

A tutorial area at the beginning of the experience allows users to explore a virtual reconstruction of our lab and learn the mechanics at their own pace. Once ready, they can select an avatar and begin the main experience.

B. Data Collection

Questionnaire and Embodiment measures – To evaluate which virtual avatar elicits the highest level of embodiment, we conducted a within-subjects study, approved by the university's ethical committee (Protocol RM-2024-837), in which 31 participants experienced all three avatars in randomized order, ensuring consistency and controlling for sequence effects.

To obtain a more comprehensive understanding of the SoE elicited by each condition, we collected both self-reported and physiological measures (EDA). Self-reported data were collected through a questionnaire implemented in Qualtrics. The questionnaire included a demographics section, which also contained questions related to prior videogame/IVR experience, followed by a section focused on embodiment-related questions. This latter section included an adapted version of the Avatar Embodiment Questionnaire by Gonzalez-Franco and Peck [8], containing only the items from the Body Ownership, Agency, Location, and Appearance subscales relevant to our study. Physiological measures were recorded using the ProComp Infiniti System. To do so, participants were required to attach two electrodes to the index and middle fingers of the left hand, secured with adjustable straps [Fig. 2].

Fig. 2: Experimental setup.

Procedure – The study was conducted in our laboratory under the supervision of at least one researcher. Upon arrival, participants received a brief introduction to the study and provided written informed consent. Then, they completed the demographics and videogame/IVR prior experience sections of the questionnaire. After that, to establish a baseline for physiological measures, participants sat in a relaxed state with sensors attached to their fingers for two minutes before beginning the experiment. Following baseline recording, we started the application. Participants went through the tutorial area and selected the required avatar. When the embodiment occurred, the researcher recorded an event in the ProComp

Infinity Software. After completing the experience, participants filled out the embodiment section of the questionnaire, indicating which avatar they had experienced. Then, they engaged in two minutes of free real-world interactions before proceeding to the next avatar, to prevent carryover effects between conditions. This procedure was repeated three times, once per each avatar. At the end of the experimental procedure, participants were engaged in a short, informal debrief, to gain qualitative insights into the application.

Hypotheses – The following hypotheses drove our study:

***HP.1* –** The three avatars will elicit different levels of embodiment, measured through the self-reported questionnaire.

***HP.2* –** The shape of the avatar and the elicited level of embodiment will cause different physiological activations, identified through the EDA measurements.

IV. Results

Our sample consisted of 31 participants (18 female, 13 male), aged between 18 and 44. The overall results are displayed in Fig. 3. Given that the application and the questionnaire were in English, we required our participants to be proficient in this language.

Data were cleaned and analyzed using the software R. All continuous variables were firstly centered and scaled to have their mean equal zero and their Standard Deviation (SD) equal one. Normality of the residuals was checked through visual inspection of the Q–Q (quantile–quantile) plots, resulting in normal distributions of both embodiment- and EDA-related data. Outliers of the independent variables were removed if they were more distant than ± 3 Median Absolute Deviations (MAD) from the median, resulting in the removal of 13 observations out of 93.

To evaluate *HP.1* we computed a Linear Mixed Model (LMM), with the overall SoE ratings as dependent variable and the avatar as predictor. We found a significant effect of the avatar on the overall embodiment score [$\chi^2(2) = 7.47$, $p = .023$], indicating that the level of embodiment varied depending on the avatar experienced. Post-hoc comparisons revealed a significant difference in overall embodiment scores between the Coral and the Crab ($t(58.1) = -2.57$, $p = .034$), with participants reporting lower embodiment when embodied in the Coral avatar.

Upon assessing differences regarding the specific embodiment subscales, we computed a series of LMMs with the embodiment subscales (Body Ownership, Agency, Location, Appearance) as dependent variables, the avatar as predictor, and participants' IDs as a random factor. We found that there was a significant difference between avatars only on the Agency subscale [$\chi^2(2) = 10.478, p = .005$], but not on the subscales of Body Ownership, Location, and Appearance (all $ps > .05$). Post-hoc tests showed a significant difference between the Coral and the Crab avatars [$t(60) = -3.207, p = .006$], with participants reporting higher agency when embodied in a Crab avatar compared to a Coral avatar.

Then, we tested *HP.2* through a LMM, which included the experienced avatar, the self-reported level of embodiment,

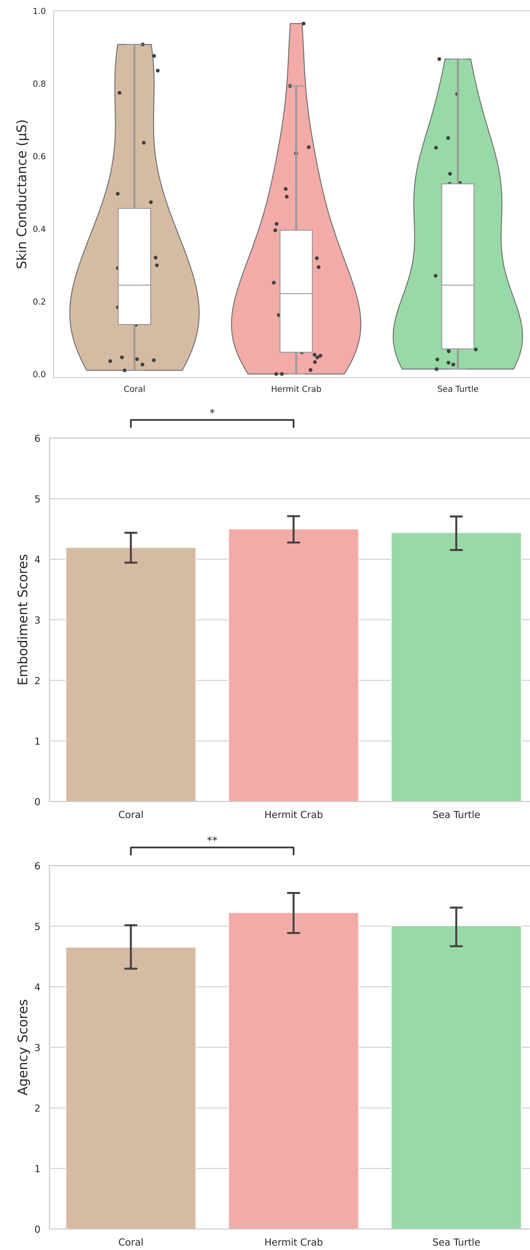

Fig. 3: Top: Avatar effect on EDA measurements; each violin depicts the full data distribution, while the white box shows the inter-quartile range with the median line, and grey jittered dots represent individual trials. Middle and bottom: Avatar effect on Embodiment (middle) and on the Agency subscale (bottom).

and their interaction as predictors. Prior IVR experience was included as a covariate, and participant ID was modeled as a random intercept. Physiological activation, computed as the sum of amplitudes of significant peaks (i.e., higher than $0.01\ mV$) during a 10-seconds window, was measured as the difference between the activation during the embodiment phase and the activation during the baseline. The baseline was recorded before the start of the IVR experience, during the relaxation phase, while the embodiment phase started 2 seconds after participants found themselves embodied in the virtual characters and ended 10 seconds later. The length of the time window was based on the literature [9] and fine-tuned after visual inspection of the data.

We found that EDA was significantly predicted by both the level of embodiment [$\chi^2(1) = 4.433, p = .035$] and the avatar displayed [$\chi^2(2) = 5.987, p = .050$]. In particular, higher levels of embodiment led to higher EDA. As for the effect of the avatar, post-hoc analyses revealed a significant difference between the Coral and the Hermit Crab avatars ($t(47.9) = 2.501$, $p = .041$), with participants showing higher EDA when embodied in a Coral than in the Hermit Crab condition. No other pairwise comparison was significant.

V. Discussion

Both self-reported and physiological measures indicated that avatar characteristics significantly affected the embodiment experience. In particular, the Coral avatar elicited higher EDA in the participants during the embodiment phase than the Hermit Crab, indicating greater physiological arousal. Conversely, self-reported measures revealed higher embodiment scores–especially in the Agency subscale, which drove the overall results–for the Hermit Crab compared to the Coral.

We hypothesize that Agency played a key role in these results. Agency is a crucial component in eliciting the SoE through virtual application [12]. In our study, the Coral avatar was designed as a static entity, offering no locomotion possibilities, whereas the Hermit Crab allowed free exploration of the underwater environment. This difference in movement likely contributed to the higher Agency participants experienced in the Hermit Crab condition, resulting in higher SoE scores. These results aligned with previous research, which associated increased Agency with stronger embodiment [12, 13]. Furthermore, as noted by Markowitz et al. [16], users who move more within a VE–especially in environmental contexts–may be more inclined to engage in pro-environmental behavior. While we did not track participants' movement patterns in this study, our findings may support the idea that stronger embodiment, driven by Agency, could enhance users' perceived ability to act within the environment and potentially promote pro-environmental attitudes. Future research is needed, to explore this hypothesis more directly.

The physiological response tells a complementary story. The higher EDA observed in the Coral condition may reflect participants' frustration with the lack of control and inability to move freely within the VE. This interpretation is supported by participants' comments during the post-experience debrief. Remarks such as *"With the limited movement of the Coral, I was not able to avoid some junk"* (Participant 27) and *"The Coral made me feel limited"* (Participant 29) express the feeling of being constrained while embodying the Coral avatar. Even though participants may have cognitively understood the Coral's movement limitations, the emotionally rich and dynamic VE likely activated a natural desire to move and explore, leading to heightened physiological arousal.

Taken together, these findings highlight IVR's potential as a powerful medium for raising awareness about climate change. They also underline the pivotal role of Agency in shaping the embodiment experience: while static embodiment may provoke strong emotional responses, as shown by physiological measures, it may not produce the same level of self-reported embodiment as more interactive forms. These results suggest that IVR applications aimed at education and behavioral change should prioritize avatars capable of movement and interaction, as these affordances significantly enhance the SoE.

VI. Conclusion

This study investigated how avatar design influences users' SoE in an underwater IVR experience, through a combination of self-reported questionnaires and physiological measures–specifically EDA.

Our findings show that avatars that enable locomotion–such as the Hermit Crab–elicit higher levels of perceived embodiment, both in the Agency subscale and in the overall results. In contrast, the static Coral avatar triggered greater physiological arousal, likely reflecting participants' frustration with restricted movement. This discrepancy between subjective and physiological responses highlights the importance of using complementary methods to fully capture the complexity of embodiment in IVR. These results reinforce the importance of Agency in shaping the embodiment experience and suggests practical implications for the design of IVR applications. Specifically, avatars that support natural movements can enhance users' engagement and presence, making them especially suitable for educational contexts focused on environmental awareness.

Future works should extend this research by accurately quantifying users' movement within the VE, correlating these patterns with both subjective and physiological responses. These measures should also be correlated with users' tendency to engage in pro-environmental behaviors, potentially including follow-up assessments of behavioral intentions–such as willingness to reduce plastic use or support marine conservation–in order to reinforce the observations of Markowitz et al. [16]. In addition, future studies should explore the reduction of the *Psychological Distance* between users and the effects of climate change, thereby enhancing emotional engagement and the perceived urgency of environmental issues. Furthermore, recent frameworks such as the Cognitive Affective Model of Immersive Learning (CAMIL) [15] suggest a positive correlation between embodiment and learning outcome in educational immersive applications. Hence, we aim to assess the educational impact of *Envisioning Corals* by evaluating learning outcomes and attitudinal changes, to gain a deeper insight on the potential of immersive learning with embodied avatars.

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