Preparing Users to Embody their Avatars in VR: Insights on the Effects of Priming, Mental Imagery, and Acting on Embodiment Experiences

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Fig. 1. Our user preparation protocol is applied before entering virtual reality (VR) in three steps: (1) The user is informed about who the character they will embody is (here, the Hulk) and how it behaves; (2) they close their eyes and perform a mental imagery task where they imagine becoming their avatar; (3) the user stands and tries to physically impersonate their avatar's character. After this process, (4) the user is immersed in their avatar's body in VR.

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Establishing a strong connection between users and their avatars in virtual reality poses an enduring challenge. Despite technical advancements, some users resist their avatars, while others seamlessly accept them as replacements for their bodies. We investigate the feasibility of pre-conditioning users to embrace their avatars prior to immersion. To do so, we propose a user preparation protocol involving three stages: first, users receive information about their avatar's identity, capabilities, and appearance. Next, they engage in a mental imagery exercise, envisioning themselves as their avatar. Finally, they physically impersonate their avatar's character through an acting exercise. Testing this protocol involved a study with 48 participants embodying an avatar representing the Hulk, with and without preparation. We could not find significant effects of the user preparation on the sense of embodiment, Proteus effects, or affective bond. This prompts further discussion on how users can be primed to accept their avatars as their own bodies, an idea introduced for the first time in this paper.

CCS Concepts: • **Human-centered computing** → **Virtual reality**; *Empirical studies in HCI*.

Additional Key Words and Phrases: Virtual Reality, Avatar, Embodiment, Proteus Effects, Priming

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1 INTRODUCTION

Virtual reality (VR) has emerged as a transformative technology, allowing users to enter immersive digital worlds and interact as avatars. A pivotal aspect of VR experiences is how well users accept their avatars as their own bodies. This bond is often measured through the *sense of embodiment* (SoE), corresponding to users perceiving themselves as not merely controlling an avatar but also inhabiting it. Providing a strong connection between users and their virtual representation promises to enrich various VR experiences, from entertainment to education and therapy. In particular, previous work has found that embodiment illusions could influence users' behaviour and perception based on the avatar's appearance [26, 32, 33]. This phenomenon, called the Proteus effect, could be exploited to "sculpt" the user for specific tasks and improve their performance [11].

While an SoE can be generated by mapping user movements onto the avatar with body tracking, this is not always sufficient to lead users to accept it as their own bodies. In fact, it is common to observe users rejecting their avatars, even with state-of-the-art technology. This difficulty is usually explained by subjective factors: depending on the user, they can lead to either a propensity to Body Ownership Illusions (BOI) or reluctance to feel embodiment [9]. Therefore, it cannot be guaranteed that a VR system will generate the same experience across users. In addition to complicating experimental research on BOIs, this variability makes it impossible for some to benefit from their effects. Indeed, "virtual embodiment of a relevant avatar is not, in itself, sufficient to induce a Proteus effect" as Ash et al. [2] wrote.

A recent meta-analysis [33] suggests that failures to replicate Proteus effects typically happen when users are not sufficiently compelled to relate to their avatars. This was mainly observed with avatars that are too "dissimilar" from users, notably in terms of appearance, gender, or emotional connection. While customising the avatar can help reduce this issue, there are many situations where changing the avatar's appearance is not desired or possible [8].

This research aims to address the challenge of creating strong embodiment experiences with dissimilar avatars in VR. To do so, we explore how to enhance the user's ability to connect with their avatar by introducing a user preparation protocol. This protocol was inspired by previous research showing that mindfulness and acting can enhance perspective-taking and empathy, which, in turn, can enhance BOIs [24, 35, 39]. The preparation, comprising three phases, seeks to enhance users' connection with their avatars by (i) informing users about the identity, capabilities, and look of their avatar before embodying it, (ii) engaging them in a mental imagery exercise where they imagine embodying the avatar, and (iii) encouraging physical impersonation of the avatar through acting (Figure 1).

The motivation behind this research lies in recognising that while the technology underpinning VR advances rapidly, the human factor remains a critical variable in the equation. Users' perception, comfort, and engagement are heavily influenced by their mental state, expectations, and the cognitive preparation they undergo before immersing themselves in a virtual environment. Our contributions can be summarised as follows:

- We propose a user preparation protocol for VR embodiment for the first time, shedding light on unexplored pathways to improving the user experience of avatars;
- We present the results of a user study involving 40 participants, evaluating the impact of our protocol on the SoE, Proteus effects, and users' affective states;
- We offer insight, theories, and research questions for future work to continue investigating strategies to enhance the user-avatar bond for VR embodiment.

As we could not find evidence of the effectiveness of the protocol we designed, we conclude with takeaway lessons and a call for continued research into the interplay between cognitive and experiential elements in VR.

2 RELATED WORK

VR research has witnessed a growing interest in enhancing the user-avatar bond and Proteus effects. This section overviews previous work on strategies to enhance embodiment illusions and literature that inspired our research.

2.1 Success Measures of Embodiment Experiences

Given the important part that avatars play in the user experience, their evaluation has been at the centre of extensive research [15, 16, 31]. Various methods have been developed to measure the "success" of virtual embodiment experiences, typically seen as how well users accept their avatars as their real bodies. The most common one is self-report measures of the SoE, referring to the sensations of being inside, having, and controlling a body [21]. The SoE emerges from both bottom-up influences, such as sensory coherence from visual, tactile, and proprioceptive inputs [36], and top-down cognitive factors, including avatar realism and self-similarity [9, 13, 16]. These components integrate perceptual and cognitive processes that can modulate emotional responses and cause Proteus effects [14, 21, 26].

Objective measures such as physiological responses (e.g., skin conductance) and behavioural metrics (e.g., task performance) have also been used to provide quantitative insights into users' engagement and immersion levels with their avatars [15, 16]. As such, Proteus effects have been used to indirectly gauge the success of BOIs. Although the mechanisms behind these effects are not well understood yet, research suggests that they are amplified by strong user-avatar bonds, defined by Ratan et al. [33] as the degree of psychological proximity or connection between the user and their avatar. This bond can be influenced by factors such as interindividual differences, wishful identification, and self-similarity [32, 33]. Additionally, when users feel a strong SoE with their avatars, they are more likely to associate themselves with the avatar's characteristics and traits [5, 26, 42]. Therefore, enhancing the SoE can result in stronger Proteus effects, but links of causality remain debated [10].

In our study, we manipulate top-down processes linked to BOIs. Our user preparation protocol attempts to strengthen the user-avatar bond by scaffolding self-identification and emotional connection. We assess the SoE and Proteus effects as key indicators of success.

2.2 Strengthening Dissimilar Avatar Embodiment

While personalising avatars to increase user similarity is often effective for enhancing SoE and Proteus effects [13, 28, 38], embodying dissimilar avatars is desirable in many situations. For instance, such avatars may be useful in therapy, gaming, to explore different identities, or when looking to induce specific Proteus effects (e.g., Albert Einstein [3], animals [1]). Additionally, customising avatars can require significant effort, especially when needing to preserve the user's identifiability while avoiding uncanny valley effects [17, 29]. Consequently, many VR applications developers opt for generic avatars despite usually resulting in lower SoE due to reduced self-similarity. Our research seeks ways of addressing this limitation of dissimilar avatars.

To address this challenge, researchers have explored methods such as visual effects to smooth the transition between one's body and the avatar. For example, Otono et al. [30] proposed visual effects like morphing and fading to show progressive change. Their user study compared the SoE and Proteus effects induced (i) with and without applying visual effects and (ii) with and without letting the participant control these transitions. They found that visual effects enhanced the sense of ownership and Proteus effects, especially when users actively controlled them. This suggests that actively involving the user in their avatar's embodiment could help instil a stronger SoE—a hypothesis we further test in this paper.

The high inter-subject variability observed in SoE studies is often explained by subjective factors including personality traits [9, 35], empathy [35], hypnotisability [25, 37], and sensory suggestibility [27]. While eliminating these factors is impossible without selective recruitment, the user's perception may be manipulated to mitigate their influence. Walsh et al. [37] were among the first to reflect on this idea and suggested using hypnosis. According to them, putting users in a hypnotic state could enhance their attentional focus on the stimulus (e.g., visuotactile stimulation), allowing for a stronger embodiment response. However, given that the effectiveness of hypnotic procedures is contingent on the user's hypnotisability and requires specialised training, hypnosis is not a practical solution for enhancing the SoE on a large scale [7]. We propose using mental imagery and acting to increase empathy and help users accept the avatar, as detailed below.

2.3 A New Strategy Based on Mindfulness and Acting

Previous work showed that avatar embodiment can create empathy towards others and influence their behaviour [43]. In the present research, we aim to verify if the opposite is also true: does building empathy and deliberately changing one's behaviour allow for a stronger connection with one's avatar? In particular, we investigated the use of activities such as mental imagery and role-playing.

Mindfulness exercises typically involve mental imagery, focusing on one's breathing and allowing thoughts to flow without attempting to suppress them. These exercises can be tailored to facilitate perspective-taking experiences and enhance empathy-related skills by guiding the user's imagination, as demonstrated in Hildebrandt et al.'s research [18]. Studies by Lueke et al. [24] notably showed that just 10 minutes of mindfulness practice can significantly reduce prejudices toward different social groups and increase empathy. A study by Romano et al. [35] with 298 participants supports the intuition that practising such exercises could be used to increase the SoE. They found positive correlations between the SoE and empathy, suggesting that those who can easily adopt other's perspective typically exhibit a stronger SoE. Therefore, augmenting the participant's perspective-taking ability seems to be a promising strategy to increase the SoE.

Likewise, acting activities can effectively nurture perspective-taking abilities [39]. Role-playing techniques were found helpful in various contexts, including therapy and conflict resolution [4]. These techniques employ a combination of physical interactions, such as participants swapping seats and storytelling, to create multisensory experiences. To our knowledge, using such practices to encourage users to embrace their avatars has not been explored. This paper presents pioneering research testing the combination of acting and mental imagery to enhance the connection between users and avatars.

3 USER PREPARATION PROTOCOL

VR embodiment experiences can be cut into three phases: the "pre-embodiment", "embodiment", and "post-embodiment" phases (Figure 2). In most BOI experiments, efforts to induce an SoE typically occur after entering the embodiment phase, when users can already perceive themselves as avatars. The post-embodiment phase is then used to evaluate the enduring effects of avatarisation on users or to gather additional subjective data. The pre-embodiment phase, on the other hand, has been underutilised. Participants are usually informed about their tasks before being put inside their avatars without further due. Hence, users must swiftly adapt to their new virtual bodies and discern their capabilities. To mitigate this friction, we propose familiarising users with their avatars in advance and mentally preparing them for the embodiment process.

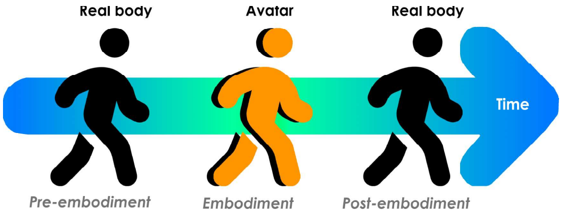


Fig. 2. Main phases of avatar embodiment experiences. *Pre-embodiment* Time before the user enters their avatar's body. *Embodiment* Time during which the user experiences and controls their avatar. *Post-embodiment* Time after the embodiment ended.

Our approach to designing a user preparation protocol combines mental imagery and acting exercises into a concise 10-minute process meant to facilitate the user's immersion in their avatar. It is important to clarify that this protocol is intended for use with avatars characterised by distinct personalities or stereotypes that users can readily emulate. Consequently, it may not be suitable for abstract avatar forms or avatars that closely mirror the user's identity. Our experimental design does not attempt to address all potential scenarios but is a foundational exploration into exploiting pre-embodiment time to enhance dissimilar avatar embodiment.

First, our preparation protocol attempts to break expectation mismatches about the avatar. Novice VR users often have preconceived ideas of what they will experience in VR, sometimes leading to confusion or disappointment and eventually to rejection of the avatar. To avoid this, we provide visuals of the 3D model and explain its capabilities beforehand. We additionally inform the participant about the character's identity, background, and the stereotypes it carries. Indeed, users may not be able to undergo Proteus effects without this knowledge [41].

Next, the participant engages in a mental imagery exercise. The instructions are provided to direct the participant's attention towards their bodily sensations, encompassing aspects such as breath, heartbeat, and skin sensations while having their eyes closed. The instructions also describe emotional states relevant to the avatar and encourage the participant to feel these emotions. Then, the participant is prompted to visualise a gradual transformation wherein their body progressively morphs into their avatar's body, basing their imagination on the visuals they were shown before.

Following this phase, the participant engages in a role-playing exercise where they enact scenarios typical of their avatar's behaviour. Through guided prompts and improvisational elements, the participant embodies their avatar's persona, integrating the knowledge gained from the preparatory stages into their physical actions and interactions. This acting experience is meant to bridge mental visualisation and physical embodiment, leading to the culmination of the participant's mental immersion in their avatar.

The overarching objective of this procedure is to actively engage the user in constructing their BOI, empowering them to lead their embodied experience. In doing so, we mean to cultivate a form of conditioning that will streamline the user's acceptation of the avatar once they embody it. The protocol outlined above can be briefly summarised in the following steps, illustrated in Figure 1:

(1) **Introduction**: The user is shown their avatar and its capabilities, accompanied by an explanation of the stereotypes it carries. The experimenter ensures the user's comprehension through targeted questions such as "Can you describe this character?" and corrects if needed.
(2) **Mental Imagery**: The user actively engages in the imaginative process of becoming their avatar. Detailed instructions encompassing both visual and emotional aspects are provided. For example, "Recall a recent experience that triggered anger or stress" or "Visualise your body gaining muscularity".
(3) **Acting**: The user physically impersonates the character their avatar represents. They receive specific instructions to assist them in the performance. For example, "Clench your fists tightly and arch your body".

Upon completion of these three steps, users are immersed in VR. We conducted a VR-based user study to assess the impact of this protocol on the resulting embodiment experience, comparing conditions with and without user preparation.

4 USER STUDY

We tested the protocol in section 3 using an avatar of the Hulk, from the Marvel franchise. This section describes the measures, protocol, apparatus, and recruited participants.

4.1 Measures

The broader goal of this user study was to test whether our approach could enhance the user's connection with dissimilar avatars. This was tested across various dimensions, including through the following subjective measures:

- **Sense of embodiment**: The SoE was evaluated through a modified version of the 16-item questionnaire developed by Peck et al. [31]. The items were tailored to align with the specific context of our experiment. This questionnaire was administered within VR, during the embodiment of the Hulk avatar.
- **Affective state**: We used the Self-Assessment Manikin (SAM) scale by Bradley and Lang [6] to measure participants' affective states across Valence, Arousal, and Dominance. It was administered upon arrival and during the VR embodiment.
- **Post-experiment feedback**: Supplementary data was collected through a custom questionnaire on a 7-point Likert scale. This questionnaire also included an optional comment section, allowing participants to provide open-ended feedback. It was administered after the session, outside of the virtual environment. The items are listed in Figure 5.

Following previous literature on the Proteus effects of muscular avatars [22, 23, 30], we hypothesised that embodying the Hulk would enhance physical performance. Therefore, we selected two tasks (rock-breaking and gripping) which generated the following quantitative data on Proteus effects:

- **Grip strength**: Measured by a hand dynamometer in kilograms. This measure was inspired by Otono et al. [30] who showed that muscular avatars could enhance grip strength due to Proteus effects. We used their procedure to obtain a ratio of "embodied" to baseline grip strength, repeating the measure to collect maximum grip strength and "goal-oriented" grip strength, where users applied just enough force to crush an object.
- **Punch speed**: The velocity of the avatar's hand upon contacting a stone was logged for each interaction, measured in meters per second. This repeated measure was introduced experimentally to explore various actions influenced by the avatar.

Since users were not explicitly directed to adopt specific behaviours within the VR environment, these two metrics were objective indicators of whether the preparatory process affected the users. Lastly, to control the impact of individual characteristics, we created a demographics questionnaire collecting age, gender, prior exposure to VR technologies, video game play time, participation in acting activities, and prior knowledge of the Hulk character (referred to as "familiarity"). We additionally controlled for simulator sickness with the 16-item questionnaire of Kennedy et al. [19], administered while in VR.

4.2 Pilot Study

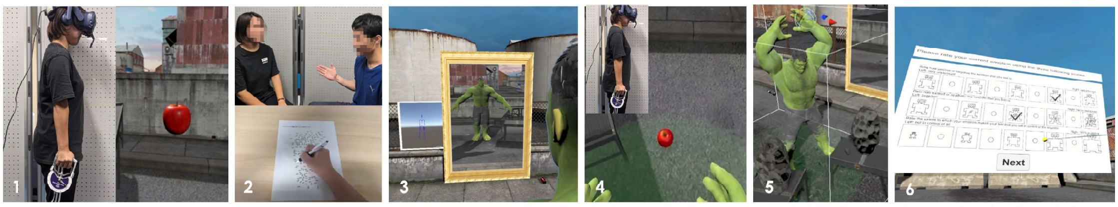
This study was preceded by a pilot trial with 13 participants, in which encouraging results were found. We observed a tendency where all SoE dimensions were increased after applying user preparation, compared to when immersing users directly. Most users also reported feeling stronger or more powerful while embodying the avatar when preparation was applied. This pilot used the same apparatus and protocol as the current study. However, it was conducted in a within-subjects design with the two conditions (with and without user preparation) separated by one week. This time interval was meant to reduce carry-over effects.

Participant feedback suggested that spacing the conditions over time did not properly eliminate carry-over effects. Some participants whose first condition included user preparation reported that, during the second condition, they recalled the preparation process and assumed they were expected to adopt the same mindset. To prevent this reasoning, we assigned participants to only one condition in the current study.

4.3 Protocol

We compared two conditions in a between-subjects design: one where the users performed an arbitrary task before the embodiment (condition "NO_PREP"), and one where they went through the preparation (condition "PREP"). The entire procedure is summarised in Figure 3, lasting around 45 minutes.

Before starting, participants received a briefing on the experiment's protocol, completed the demographics questionnaire, and had their baseline grip strength measured. Maximum grip strength was collected by asking participants to clench their fists as hard as possible using a hand dynamometer. Then, goal-oriented grip strength was measured in VR (without embodying an avatar) by showing them a virtual apple and asking them to grip the dynamometer just firmly enough to crush the apple (Figure 3.1). Participants were then randomly assigned to one of the following options:



Baseline grip strength measure | PREP or NO_PREP | Visuomotor stimulation | Grip strength measure | Rock-breaking task | Sense of embodiment, SAM, cybersickness questionnaires

Fig. 3. Overview of the experiment's procedure. 1) Baseline grip strength (maximum and goal-oriented) is measured using a hand dynamometer. 2) Condition PREP or NO_PREP is applied. 3) The participant is immersed in VR and goes through visuomotor stimulation. 4) The grip strength is re-measured. 5) The participant proceeds to the rock-breaking task. 6) Finally, they complete an SoE, SAM, and cybersickness questionnaire before exiting VR.

- **"NO_PREP" (control condition)**: participants solved a puzzle for 12 minutes (Figure 3.2, bottom). They were informed that their performance was not being evaluated and told they would subsequently embody an avatar representing the Hulk in VR without additional information.
- **"PREP"**: participants underwent the three-stage process of the preparation detailed in section 3 for approximately 12 minutes (Figure 1). Before that, they received a comprehensive briefing on the preparatory process, which included information about the forthcoming embodiment of the Hulk in VR. For more details on the instructions, please refer to Appendix A.

Following this, participants underwent the same procedure in either condition. They put on the VR equipment and closed their eyes as the experimenter initiated the software and calibrated their avatars. Then, they briefly acclimated themselves to their Hulk body in a first-person perspective. Next, the experimenter instructed them to face a virtual mirror and replicate gestures from a video alongside it (Figure 3.3). These gestures included simple arm and leg movements repeated over two minutes to elicit visuomotor stimulation. This procedure was inspired by previous work by Wolf et al. [40], and Waltemate et al. [38].

At the end of this phase, participants' maximum and goal-oriented grip strength were measured again while seeing their virtual bodies (Figure 3.4). The rock-breaking task then began: participants faced conveyor belts next to them and broke stones that they transported (Figure 3.5). A total of 30 stones were conveyed over 1.5 minutes. If a participant punched forcefully (surpassing a threshold determined through experimental prototyping), the stone shattered into fragments, accompanied by sound and controller vibrations. The force threshold was consistent for all participants.

Lastly, the participants were asked to answer the SoE questionnaire, SAM scale, and cybersickness questionnaire through an interface in VR (Figure 3.6). The participants could select answers using hand rays. Once done, the experimenter unequipped the user and invited them to complete the post-experiment questionnaire.

4.4 Apparatus

System Description. An HTC Vive Pro connected to a high-performance PC configuration was employed for our setup. This PC featured an NVIDIA GeForce RTX 2080 Ti graphics card, an Intel Core i9-9900K processor, and 32 GB of RAM. We strategically positioned HTC lighthouses within a room measuring approximately 9 square meters at opposing corners. A 5-point body tracking was performed including the head, hands, and feet position thanks to wearable Vive trackers. The experimental software was developed using Unity 2020.1.4f1, integrating SteamVR and the

FinalIK v2.1 plugin created by Pärtel Lang. To present questionnaire material within the VR environment and record user responses, we leveraged the VR Questionnaire Toolkit developed by Feick et al. [12].

Avatar selection. We opted for the Hulk from the Marvel franchise for several reasons: he is a globally well-known and highly stereotypical character, defined by his rage and physical strength. Unlike characters with more nuanced body language, the Hulk's straightforward demeanour made him an intriguing and accessible choice for our study. We used a free model by Muhammad Awwad (Figure 4, right) rigged for animation and containing detailed body textures.

Calibration and animation. Animation clips were created to allow users to clench their fingers by pressing the hand controllers' triggers. Other body movements were controlled through body tracking and inverse kinematics. The avatar underwent a two-step calibration process: first, the user's height was scaled using the VR headset's tracked position, and then the FinalIK plugin was used to calibrate arm and leg lengths and adjust the user's camera position. Additional adjustments were made to target points associated with the head, hands, and feet if needed. Finally, the resulting avatar was scaled back to the Hulk's original dimensions (2.5 m height).

Virtual environment. The VR environment replicated a realistic industrial area using open-source assets (Figure 4, left). It included life-sized objects like soda cans for users to gauge their body's size. A mirror allowed users to see their full avatar. Two conveyor belts transported breakable stones for the rock-breaking task. The environment had ambient noise resembling construction work and provided audio and haptic feedback when users interacted with the stones. Feedback intensity was adjusted based on interaction force. Participants were instructed to move on the floor in a demarcated green circle to avoid collisions with real-world objects.

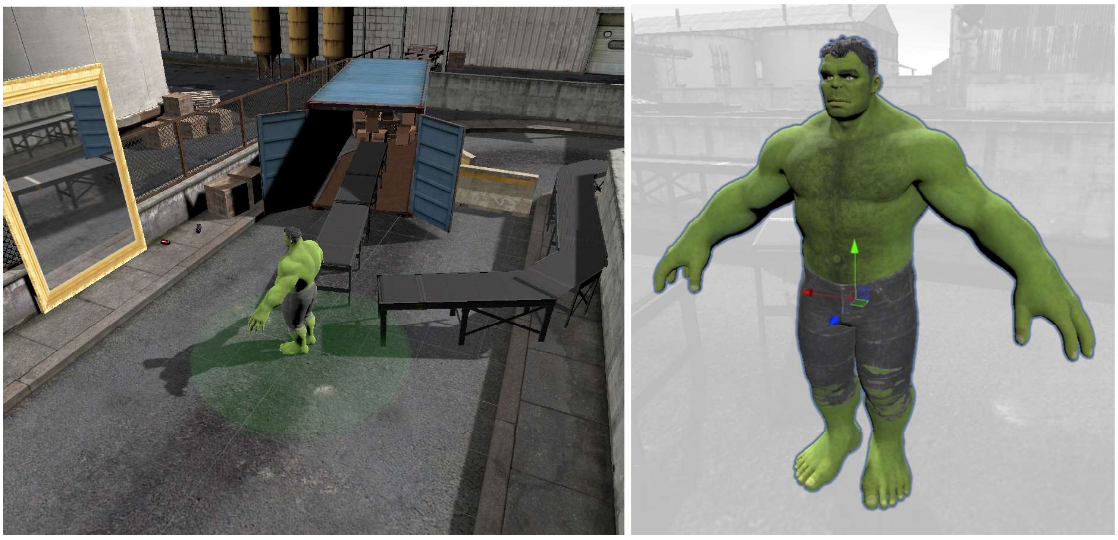


Fig. 4. *Left* Overarching view of the VR environment, comprising a mirror, two conveyor belts, and various objects recreating an industrial setting. The green zone on the floor delineated the permissible area for user movement. *Right* Hulk model used in the experiment.

4.5 Participants

We recruited 48 participants and randomly assigned them to either condition while balancing for gender, resulting in 13 males in each condition. Participants were aged from 19 to 52 years old ($\overline{m} = 23.8, SD = 4.5$). Among them, 57.5% had used VR headsets once or twice, 15% used them a couple of times per year, 20% never, and 7.5% had a frequent usage history. Regarding their participation in acting activities (theatre, role-playing, etc.), 77.5% had never done any before. Results on prior familiarity with the Hulk showed 40% did not know this character at all, 35% knew about it, 20% had watched at least one movie featuring it, and 5% indicated knowing it well from movies or comics. The video game play time was less than 1 hour per week for 37.8% of participants, between 1 and 5 hours for 31.3%, and over 5 hours for the rest. The participants were paid 1,000 Japanese yen at the end of the session. All were unaware of the experiments' purpose. A local ethical committee approved this experiment.

5 ANALYSIS AND RESULTS

Eight participants were excluded from the analysis due to technical issues in data collection, leaving 40 participants (20 per condition). We used R to identify differences in the SoE scores, SAM scores, and Proteus effects (grip strength, punch speed) across conditions. We also performed a descriptive analysis of the items in the post-experiment questionnaire. A p-value less than 0.05 was considered statistically significant. Additional plots are provided in the Appendix.

5.1 Control Measures

We tested whether our control measures significantly impacted any dependent variables and verified their independence from predictor variables. When the impact was found significant, these control measures were added to the models described in the next subsections.

A repeated-measures ANOVA showed that the user's prior knowledge of the Hulk (i.e., familiarity) had a significant effect on the punch data, $F(3, 36) = 5.49, p = 0.003$. A chi-square test of independence was then conducted. The test revealed a significant association between familiarity and condition, $\chi^2(3, 40) = 35.1, p < 0.001$. This result indicates familiarity may confound the effect of the condition on the dependent variable (punch speed). To address this, familiarity is controlled in the main analysis by including it as a covariate. Familiarity did not have a significant effect on any other dependent variables (SoE, SAM, grip, post-experiment questionnaire items).

A Wilcoxon rank sum test showed that the participant's gender had a significant impact on item 5 of the post-experiment questionnaire, related to the engagement (Figure 5), $W = 256, p = 0.03$. However, a chi-square test of independence showed no significant association between gender and condition ($p = 1$). Therefore, we do not include it in our analysis of this item. Gender did not significantly impact any other dependent variables.

Finally, we could not find significant effects of prior VR experience, video game playtime, prior acting experience, age, or cybersickness on any of our dependent variables. Therefore, they were not included in our main analysis.

5.2 Sense of Embodiment

Following the methodology outlined by the questionnaire's creators [31], the SoE questionnaire responses were used to calculate five scores: Appearance, Response, Ownership, Multisensory, and Global Embodiment. Table 1 details these scores. The two conditions successfully elicited an SoE, as the median score values are above four for all dimensions. The medians of PREP and NO_PREP are similar for all scores, varying by 0.4 points at most.

Table 1. Sense of embodiment scores. Median, first (Q1) and third (Q3) quartiles are reported as follows: Median[Q1,Q3].

Condition	Appearance	Response	Ownership	Multisensory	Embodiment
NO_PREP	4.4[4.0, 4.9]	4.9[4.0, 5.4]	4.9[4.4, 5.2]	5.3[4.3, 5.7]	4.8[4.3, 5.3]
PREP	4.8[4.1, 5.1]	4.8[3.8, 5.5]	4.6[4.0, 5.5]	5.0[3.9, 5.7]	4.8[4.0, 5.5]

Levene's tests showed that each dimension's variance was homogeneous for all groups ($p > 0.05$). Q-Q plots indicated that the data points of each score align well with the theoretical quantiles of a normal distribution. Shapiro-Wilk tests further confirmed that residuals do not significantly deviate from normality for all groups ($p > 0.05$), except for the Multisensory score ($W = 0.93, p = 0.02$). Therefore, we used independent measures t-tests for all scores except Multisensory, for which we used a Wilcoxon rank sum test. The t-tests could not show any significant effect of the conditions on the Appearance, $t(36) = -0.57, p = 0.57$, Response, $t(37) = -0.18, p = 0.85$, Ownership, $t(37) = 0.43, p = 0.67$, or Embodiment scores, $t(35) = 0.06, p = 0.95$. The Wilcoxon rank sum test also could not show any significant effect on the Multisensory score, $W = 210, p = 0.81$. Therefore, we could not validate our hypothesis that the user preparation would significantly increase the SoE.

5.3 Affective state

SAM during the embodiment ($t2$). We compared the SAM measures collected during the avatar's embodiment across conditions. Levene's tests showed that the population variances were homogeneous ($p > 0.05$ for all dimensions). The SAM data being of an ordinal nature, Wilcoxon rank sum tests were applied on each dimension. No significant differences were found across our conditions for Valence $U = 198, p = 0.097$, Arousal, $U = 207, p = 0.85$, and Dominance, $U = 208, p = 0.83$.

SAM delta ($t2 - t1$). We looked at the evolution of the SAM ratings over time by computing the differences in SAM scores before the user preparation ($t1$) and during the embodiment ($t2$) for each condition.

$$\Delta_V = \quad Valence_{.t2} - Valence_{.t1} \tag{1}$$

$$\Delta_A = \quad Arousal_{.t2} - Arousal_{.t1} \tag{2}$$

$$\Delta_D = \quad Dominance_{.t2} - Dominance_{.t1} \tag{3}$$

Levene's tests showed that the variances are homogeneous ($p > 0.05$ for all dimensions). As before, we applied a Wilcoxon rank sum test for each dimension. We found no significant effect on Δ_V, $W = 145, p = 0.13$, Δ_A, $W = 143.5, p = 0.12$, or Δ_D, $W = 227.5, p = 0.46$.

SAM within subjects ($t2$ vs. $t1$). To further investigate changes in affective state, we compared the SAM data collected before and during the embodiment for each condition separately. A Levene's test showed that the population variances of the SAM data at $t1$ are homogeneous, except for the Dominance dimension ($p > 0.05$ for Valence and Arousal, $p = 0.03$ for Dominance). As before, we applied a Wilcoxon rank sum test on each scale dimension. In NO_PREP, the results show that Arousal was significantly higher at $t2$ than $t1$ with a large effect size, $p = 0.01$, $r = 0.573$, $stat = 22$. No significant difference was found for Valence ($p = 0.13$) and Dominance ($p = 0.06$). In PREP, Arousal was significantly higher at $t2$ than $t1$ too, with a large effect size, $p < 0.001$, $r = 0.847$, $stat = 0$. The Dominance ratings were also significantly lower at $t2$ than $t1$ with a medium effect size, $p = 0.03$, $r = 0.512$, $stat = 136$. No significant difference was found for Valence ($p = 0.13$).

5.4 Post-experiment questionnaire

Figure 5 shows the post-experiment questionnaire's items and their answers. Generally speaking, both conditions generated positive feedback on the engagement (item 5). Many commented that the rock-breaking task was "fun" and "stress-relieving", which contrasted with the feeling of anger we attempted to induce during the user preparation. In fact, in both conditions, only 35% of them reported feeling angry or wild during the embodiment (item 3).

Spearman correlation tests were applied for each condition to detect answer patterns. In NO_PREP, the feeling of being in a costume (item 4) was negatively correlated to the feeling of being angry or wild (item 3), $r = -0.53, p = 0.02$. In PREP, the feeling of being stronger or more powerful (item 2) was positively correlated to the feeling of being angry or wild (item 3), $r = 0.68, p = 0.001$, negatively correlated to the feeling of being in a costume (item 4), $r = -0.56, p = 0.01$, and positively correlated to engagement during the punching task (item 5), $r = 0.74, p < 0.001$. The feeling of being angry or wild (item 3) was also positively correlated to this engagement (item 5), $r = 0.60, p = 0.005$. Finally, The feeling of being in a costume (item 4) was negatively correlated with the engagement (item 5), $r = -0.47, p = 0.04$.

Wilcoxon rank sum tests were applied on each questionnaire item to compare answers across conditions. No significant difference was found for any of the items: Q1, $W = 184, p = 0.67$, Q2, $W = 208, p = 0.83$, Q3, $W = 155, p = 0.22$, Q4, $W = 159.5, p = 0.27$, Q5, $W = 193.5, p = 0.86$, Q6, $W = 230.5, p = 0.41$, Q7, $W = 168.5, p = 0.39$.

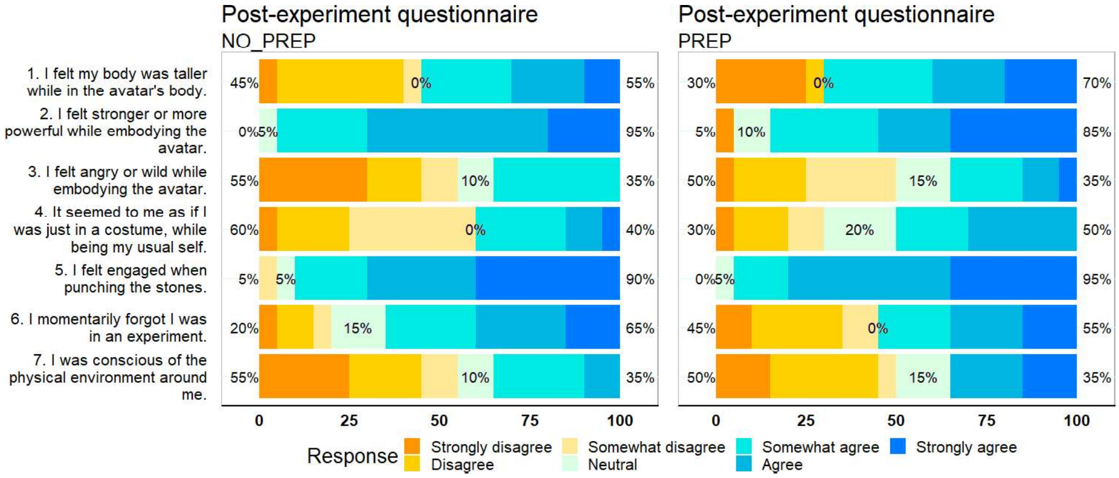


Fig. 5. Results of the post-experiment questionnaire (translated from Japanese) in the NO_PREP (left) and PREP (right) conditions.

5.5 Grip strength

Following Otono et al.'s [30] method, the following grip strength ratios were computed:

$$GS_{max} = \frac{GS_{hulk\_max}}{GS_{baseline\_max}} \tag{4}$$

$$GS_{apple} = \frac{GS_{hulk\_apple}}{GS_{baseline\_apple}} \tag{5}$$

In other words, GS_{max} corresponds to the normalised maximum grip strength, whereas GS_{apple} corresponds to the normalised grip strength used to crush an apple.

Levene's tests showed that variances were homogeneous ($p > 0.05$ for both). Q-Q plots suggested that the data aligns well with a normal distribution. Shapiro-Wilk tests further confirmed that the residuals do not significantly deviate from normality ($p > 0.05$ for both). Therefore, we performed independent measures t-tests on both grip ratios. We could not find significant differences across conditions for GS_{max}, $t(38) = 1.23, p = 0.23$, or for GS_{apple}, $t(38) = 0.81, p = 0.43$.

5.6 Punch speed

The dataset contained multiple entries for each participant, corresponding to each time they touched the rocks. As some entries might not have been actual punch intentions but involuntary contact with the rock, we eliminated these entries by filtering out values below 1 m/s. The average speed in NO_PREP was 7.78 m/s, whereas it was 9.66 m/s in PREP.

Because repeated measures were collected within subjects for punch speed but conditions were applied between subjects, we opted for a mixed model analysis. We included the condition as a fixed effect and the participant's ID as a random effect with a random intercept, as well as familiarity as a covariate. A Levene's test showed that variances were homogeneous ($p > 0.05$). Q-Q plots showed heavier tails than the normal distribution, suggesting that the data does not meet normality assumptions. A Shapiro-Wilk test further confirmed that the residuals significantly deviated from the normal distribution ($W = 0.98, p < 0.001$). Therefore, we used an aligned rank transform (ART) ANOVA. This test did not show any significant effect of the condition on punch speed, $F(1, 32) = 1.46, p = 0.24$. On the other hand, we confirmed the confounding effect of familiarity, $F(3, 32) = 5.38, p = 0.004$. No significant interaction between familiarity and conditions was found, $F(3, 32) = 2.51, p = 0.08$, but a small tendency can be observed in Figure 6.

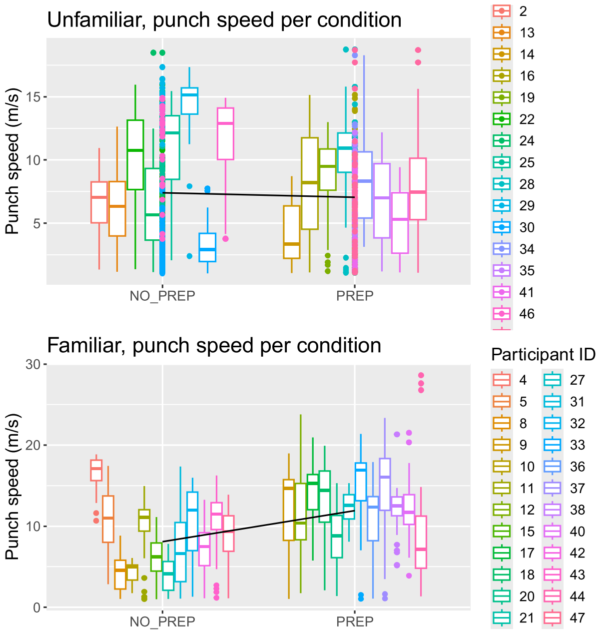


Fig. 6. Boxplots showing the punch speed and regression line for each condition, for unfamiliar (top) and familiar (bottom) participants.

6 DISCUSSION

While extensive research on BOIs exists, little work has looked into how the user may actively contribute to create them. This paper proposed using pre-embodiment time to prepare users to accept their avatars. We developed a three-stage protocol and conducted a study examining its impacts on the SoE, Proteus effect, and affective bond. Our protocol involved familiarising users with their avatars, performing a mental imagery task, and engaging in an acting task. We hypothesised that this active participation in the embodiment process would contribute to the avatar's acceptation.

We could not find significant effects of our protocol on the SoE or on Proteus effects, measured through the user's grip strength and punch speed. We also could not find significant effects on the user's affective state or on subjective feedback. Therefore, we could not prove our intuition that preparing users through this process would benefit the experience of the avatar along these dimensions. These results are discussed in the following paragraphs.

6.1 Absence of Significant Effects

Given that the SoE was measured towards the end of the VR exposure, there is a possibility it might have been enhanced only for a short period after putting on the headset and that it was smoothed or flattened later. The visuomotor stimulation and rock-breaking task might also have caused a ceiling effect, increasing the SoE to reach its maximum by the time it was measured. This cannot be verified as we did not collect SoE data at the beginning of the VR exposure.

The between-subjects design of our experiment might have also made differences challenging to observe. This type of design usually requires large sample sizes, and our study was limited to 40 participants. However, research by Richard et al. [34] has shown that small to medium effects on the SoE are much harder to detect with between-subject designs even with large sample sizes. This is because participants cannot compare their experiences easily. Therefore, it may be the case that the protocol's effect was too small to be detected in a between-subjects design. While we were aware of this, our pilot tests evidenced important risks of transfer effects from one condition to the other.

Next, one should note that we did not collect data on the participants' height and cannot verify whether taller participants may have responded differently due to interindividual differences. Previous work suggests that self-similarity can enhance the SoE and Proteus effects [32, 33], so it is possible that shorter participants experienced a weaker "closeness" with their avatar. That being said, the Hulk's 3D model was 2.5 meters high (well above local average), and a height increase would likely have been noticeable by all participants, tall or short. The same can be commented about the participants' differences in muscularity. This raises interesting questions about what characteristics fundamentally trigger Proteus effects for a given avatar, and if some of them are more important than others.

Lastly, these results could suggest that the protocol has no real impact on the acceptation of the avatar. The SoE is thought to result from a confluence of top-down and bottom-up factors [21]. Bottom-up information arises from the coherence of visual, tactile, and proprioceptive inputs, which are defined by the technical system. Conversely, top-down information is derived from cognitive processing related to the avatar's visual characteristics, such as its resemblance to oneself and its level of realism. Asking users to actively imagine becoming their avatar and physically impersonate it was an attempt to leverage top-down mechanisms to enhance the SoE (and Proteus effects, as a consequence). The fact that we did not find significant results may be because this protocol fails to manipulate the appropriate top-down processes. We encourage future work to test this theory: confirming what works and what does not to increase the user-avatar bond will allow generating actionable guidelines when designing embodiment systems.

6.2 Familiarity Confound

Our analysis revealed that the punch speed was influenced by the level of familiarity of users with the Hulk, regardless of the condition. These results highlight the importance of culture and subjectivity on Proteus effects. We recommend future work to compare these effects when elicited by avatars of famous characters against generic avatars while controlling for the user's prior knowledge. If our theory is confirmed, stronger Proteus effects could be induced by adapting the avatar's choice based on local culture. For example, a One Punch Man character in Japan might be more well-known than the Hulk and more efficient in inducing Proteus effects on strength, but also than generic avatars.

6.3 Affective Bond

We hypothesised was that the protocol would lead the participant's affect to reflect the one that they inferred from the Hulk. As the protocol introduced this character as a raging, powerful one, and then instructed the participants to imagine feeling the same, we expected them to respond with lower Valence (linked to negative feelings), higher Arousal (linked to agitation), and higher Dominance (linked to an increased sense of power) during embodiment.

We could not find significant effects across conditions on any of the dimensions or on how they evolved (delta values). SAM values collected before and during the embodiment were compared within subjects to further explore changes in affective state. For both conditions, this comparison showed the expected increase Arousal, but not the expected decrease in Valence and increase in Dominance. In fact, Valence was significantly increased and Dominance decreased in PREP. This suggests that simply embodying the avatar was probably enough to arouse the user and lead to positive emotions. Therefore, it seems unlikely that the decrease in Dominance in PREP was linked to the perception of Hulk's nature. Rather, this could be explained by the common disorientation that can be experienced in the VR environment.

6.4 Subjective Feedback

Despite the lack of significant differences across our conditions, the post-experiment questionnaire reveals an interesting insight into how the preparation might have influenced the user experience. First, it seems that the perception of being taller was increased by 15 points in PREP, suggesting that some participants might have felt a stronger proprioceptive shift compared to NO_PREP. Next, while more participants strongly agreed to feel stronger or more powerful in PREP (35% against 20%), more participants also strongly disagreed (5% against 0%), indicating a polarisation of answers. A similar observation can be made about the perception of body height (item 1). This could suggest the existence of "receptive" and "rejecting" user clusters.

The correlation analysis shows answers consistent with this idea: participants who reported feeling stronger or more powerful also reported feeling angry or wild, engaged in the punching task, and not feeling like the avatar was just a costume (and vice versa). Given the significant effect of familiarity on the punch speed, one could expect it to also influence these items. However, our tests did not show significant results in this regard and the variance may be due to subjective parameters that we did not identify.

Lastly, more participants seemed conscious that they were in an experiment in PREP (45% of disagreement with item 6 against 20% in NO_PREP). This could be due to them knowing that their subjective experience was being tested. The experiment's purpose was not disclosed explicitly, but it is likely that they partially figured out some of our goals. This is supported by the fact that 35% of the participants reported being angry or wild in both conditions despite only 2 participants having reported negative SAM Valence values (below 5) in VR. That being said, the SAM is a minimalistic measurement tool for global affective states, and interpreting user emotions must be done with caution.

6.5 Takeaway messages

While our study did not yield significant results regarding the impact of the preparation protocol, it does not conclusively indicate the lack of any effects. Several key insights and implications emerge from our research:

- **Priming**: Informing users about their avatar, engaging them in mental imagery, and encouraging physical impersonation may not be manipulating the right top-down factors to influence the user's embodiment experience. Seeking inspiration from priming and self-perception theories could lead to more effective strategies, which we recommend investigating.
- **Difficulty**: The difficulty of performing mental imagery and acting may also have varied across users. We advise ensuring that the chosen priming method is adequate by controlling relevant subjective factors.
- **Delivery**: Applying the user preparation in person before the embodiment may have hindered potential results. We suggest exploring delivery methods that do not require the experimenter to be present and investigating how to apply the preparation directly in VR. The latter could help prevent a break in the user's mind flow when putting on the VR equipment.
- **Cultural Background**: Controlling for the user's prior knowledge of the chosen avatar's identity is necessary when studying Proteus effects linked to specific characters. We recommend selecting participants who are sufficiently familiar with the character during the recruitment phase.
- **Proteus Effect**: Predicting the types of Proteus effects that an avatar will generate is difficult. The Hulk was used for the first time in this study and was assumed to generate similar Proteus effects to those of muscular avatars used in previous literature. Until guidelines are created to better identify which Proteus effects an avatar will render, we propose using avatars whose Proteus effects have been identified in previous studies.
- **Replicability**: On the same note, previous work almost consistently uses different avatar models and types, making the replication of results difficult. We recommend using open-source avatar models as we did. This will maximise the possibility of having the preparation protocols tested by other researchers and increase the strength of the results.

6.6 Limitations

All things considered, it is challenging to tell the extent to which participants played along the instructions. In the introduction step, the experimenter ensured participants had baseline knowledge of the Hulk by asking them to describe the character. During the acting part, the experimenter could also visually check if participants followed instructions, provide feedback, or observe improvisation. For mental imagery, on the other hand, it was impossible to confirm whether they were able to imagine what the experimenter described. Some individuals may lack the same abilities to mentally visualise situations or evoke feelings [20]. The current study did not assess participants' mental imagery and empathy skills beforehand. Thus, completing our tasks may have been more challenging for some participants.

It is also possible that the duration, delivery, or format of the user preparation was not optimal. As this is a novel protocol, we lacked references to decide the best duration for each task and the types of instructions needed. Our procedure lets the experimenter stand in the room with the participants during the preparation. Some might have felt shy or embarrassed while impersonating the Hulk, which could have affected the results. Given the subjective feedback collected after the VR embodiment, we have to consider that the instructions might have negatively impacted some participants: 10% more participants agreed to the statement "It seemed to me as if I was just in a costume while being my usual self" in PREP compared to NO_PREP. This is reflected in the slightly increased inter-quartile range of the SoE global score and some SoE components (Ownership, Multisensory) in PREP.

6.7 Future work

This paper paves the way for future research on how preparing users to embody dissimilar avatars may benefit their experience in VR. In the direct next steps, we suggest replicating this study to investigate whether ceiling or plateau effects were reached in our results. This would bring light to how the impact of user preparation evolves over time and provide a more nuanced understanding of the limitations or boundaries of this protocol. Furthermore, conducting replications with a diverse range of participants and tasks could offer insights into why this protocol was ineffective. Future studies should try to extend the duration of VR exposure, as the limited time participants spent in VR may have restricted their ability to fully internalise the Hulk persona.

Secondly, the confounding effect of prior knowledge on Proteus effects has raised an interesting question regarding the potential impact of cultural backgrounds. Could avatars that are more culturally aligned with the sample population influence the efficacy of this protocol and the overall embodiment experience? We suggest investigating whether selecting an avatar that resonates more closely with the target user group allows a higher relatability with the avatar. This could contribute to a more inclusive and immersive VR environment, catering to users' diverse needs and expectations from varying cultural backgrounds.

Along the same lines, an important consideration for future work is the potential impact of social interactions on the effectiveness of user preparation protocols. In this study, participants were immersed individually, but interacting with others in the virtual environment could have heightened their awareness of the avatar's physical traits. Embodying a powerful avatar like the Hulk in the presence of others may amplify behavioural changes, such as increased assertiveness or dominance, due to social comparison. Future studies should explore the role of social interactions—either with identical or different avatars—to better understand how these dynamics interact with user preparation protocols and influence embodiment experiences.

Finally, regardless of the uncertainties arising from this study, we believe that investigations on pre-embodiment user preparation are worth pursuing. Indeed, this study is just the initial foray into exploring its potential to enhance avatar embodiment in VR. There is ample room for further refinement, but also many other strategies to explore to prime users. In addition, it would be especially interesting to investigate whether an alternative design of this protocol could be used to cancel Proteus effects rather than to increase them. This would be useful in situations where undesired Proteus effects might occur (e.g. aggressivity, bias).

7 CONCLUSION

In immersive VR, providing users with a deep sense of connection with avatars remains a significant challenge, especially when the avatar looks very different from its user. This study investigated how to address the low acceptation of dissimilar avatars by introducing a user preparation protocol. This protocol involves briefing users on their avatar's characteristics, engaging in mental imagery, and participating in acting exercises. To test its effects, we ran a study where 48 participants embodied an avatar representing the Hulk. Our study results could not show that this approach effectively influenced the avatar's acceptation. On the other hand, we observed that prior knowledge about the Hulk had a positive influence on one of our measures of Proteus effects (punch speed). Beyond appearance, this prompts further research on avatar identity as a potential top-down factor contributing to Proteus effects.

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