“If It’s Not Me It Doesn’t Make a Difference” – The Impact of Avatar Personalization on User Experience and Body Awareness in Virtual Reality

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Figure 1: Example of two study conditions using customized avatars (left) or personalized avatars (right).

Abstract

Body awareness is relevant for the efficacy of psychotherapy. However, previous work on virtual reality (VR) and avatar-assisted therapy has often overlooked it. We investigated the effect of avatar individualization on body awareness in the context of VR-specific user experience, including sense of embodiment (SoE), plausibility, and sense of presence (SoP). In a between-subject design, 86 participants embodied three avatar types and engaged in VR movement exercises. The avatars were (1) generic and gender-matched, (2) customized from a set of pre-existing options, or (3) personalized photorealistic scans. Compared to the other conditions, participants with personalized avatars reported increased SoE, yet higher eeriness and reduced body awareness. Further, SoE and SoP positively correlated with body awareness across conditions. Our results indicate that VR user experience and body awareness do not always dovetail and do not necessarily predict each other. Future research should work towards a balance between body awareness and SoE.

Keywords: Virtual reality, embodiment, personalization, body awareness, virtual body ownership, avatars, user experience.

Index Terms: Human-centered computing—Empirical studies in HCI; Virtual reality; Usability testing;

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1 Introduction

Virtual reality (VR) is a powerful tool for presenting novel environments and unique bodily experiences to users. It can trigger physical fear responses [25], induce a change in body weight perception [55, 81], or create compelling new worlds that respond flexibly to the user’s bio-signals [43]. Thus, VR offers possibilities beyond reality. It has been considered for years to support therapy. Initially, the main focus of therapeutic VR applications has been on phobias or addiction. However, there is a growing interest in mind-body interventions, which aim to improve mental health by addressing the connection between bodily experiences and well-being. In recent years, numerous VR applications have emerged specifically designed to enhance mindfulness, body awareness, and overall mental health.

Research on VR in mind-body interventions mainly focuses on therapeutic targets, while effects on users’ mindfulness are rarely addressed [19]. Especially body awareness, a part of mindfulness closely related to well-being that contributes to mind-body interventions’ success, has yet to be targeted sufficiently [3]. It has yet to be addressed how mindfulness and body awareness are affected by and how they reiterate the more general user experience in VR (VR UX). This includes, for example, the sense of presence (SoP) in a virtual environment, or the sense of embodiment (SoE) towards one’s virtual body [19]. Moreover, little has been investigated regarding the use of virtual avatars and their visual appearance in this therapeutic field. In other research fields, avatar appearance, especially the similarity between a user and their avatar, has been shown to impact the user’s SoE [78] or their health behavior [59]. However, there is still a lack of connecting the SoE and other VR UX measures with the respective target behaviors [59, 79] or underlying experiences, such as body awareness.

To address these gaps, we present a study focusing on how body awareness, as a body-centered aspect of mindfulness and as an underlying structure in mind-body therapies, relates to virtual body

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appearance and common VR UX measures. The work draws on substantial prior work on photorealistic personalized avatars. It investigates whether the degree of avatar individualization affects body awareness, avatar-related UX, and, more generally, VR UX. Based on the BehaveFIT framework by Wienrich et al. [79], we investigate the following research questions:

1. Does the degree of individualization of an embodied avatar impact body awareness and VR UX in a VR mind-body exercise?
2. Does VR UX affect body awareness?
3. Does the degree of avatar individualization impact the relationship between VR UX and body awareness?

Participants embodied a generic realistic same-gender avatar, a customized avatar using a custom avatar selection system, or apersonalized, photorealistic scan avatar. In VR, they perform repetitive movements from Basic Body Awareness Therapy [30]. We assessed body awareness, mindfulness, and various avatar-related and avatar-unrelated VR UX measures. The paper contributes to the understanding of avatar embodiment for therapy by demonstrating the extent to which realistic low-cost customized avatars affect body awareness in a virtual environment compared to photorealistically personalized avatars. In therapeutic settings, maximum personalization of avatars is not always possible. We contribute to determining the trade-off between avatar design and possible consequences for body awareness. Further, we place body awareness in a VR exercise in the context of standard VR UX measures, including SoE and SoP.

2 Related Work

According to the theory of embodied cognition, all thoughts and feelings arise from physical experiences. While our body allows us to connect, perceive, and interact with our environment, the perception of our body itself is also an essential and multifaceted component of our experience. Body awareness, the attention we pay to the perception of our body, often summarized as interoception or paired with proprioception, is an object of observation that has aroused broad interest over the years. Especially attention to the inside of the body has been associated with several psychosomatic benefits. It is operationalized via interoceptive accuracy, the ability to feel one's heartbeat [62], or via subjective self-assessment to notice, be aware of, regulate and trust body perceptions [47]. High body awareness is negatively related to depression and anxiety [18], pain and fatigue [27, 64], suicidality [32], or eating disorder symptoms [9]. Mind-body therapy success, attributed initially to mindfulness, is increasingly attributed to body awareness as a core impact [28].

2.1 The Transbodily Experience of Embodying an Avatar

The experience of simultaneously having and being a body has been the topic of numerous research [34, 56]. Various studies have investigated how we experience embodiment not only towards our natural body but also to artificial objects, such as in the Rubber Hand Illusion [71], or toward virtual bodies, avatars, in VR [52], delving into their impact on behaviors and therapeutic outcomes. The feeling we experience towards an avatar has been described as a virtual SoE [38]. To what extent such SoE equals the experience of being and having a physical body remains unclear. Being a body implies perceiving and interacting with the environment [77]. Being a virtual body would thus translate into the avatar allowing us to perceive the virtual environment. This statement does not hold, as in VR, our physical body still is the source of our perceptions and actions. However, our virtual body can induce a sense of agency [38, 60].

Embodiment further includes having a body, a perceivable physical entity representing us in an environment [77]. This concept translates more directly into the embodiment of avatars. Aligning the avatar as a virtual object and self-representation in VR with the natural body is pivotal for the SoE. The avatar's appearance, including gender, race, and realism, is decisive for this alignment. Depending on the appearance and behavior of the avatar, having a virtual body can elicit a sense of virtual body ownership (VBO) [38].

The embodiment of avatars extends the perception of simultaneously having and being a body to simultaneously having a set of bodies while still being one. VR offers the possibility of visually replacing, enriching or superimposing the physical body at will with the targeted representation of a virtual body. Body movement tracking systems allow the virtual body to follow the user's physical movements precisely and elicit a feeling of agency over the virtual body, which mixes in with the sense of VBO [38, 60]. As the visual perception of the virtual body integrates with the perception of the physical body, the focus of attention shifts toward the visible body, and the perception of actual body posture [75], movement speed or direction [36], body size [39, 81], or visual appearance [54, 57] recedes into the background. It is unclear to what extent users experience the virtual body as a part, extension, or substitute of the physical body or to what extent the perception of the virtual body contributes to a sense of change in the physical body [60]. Nevertheless, this transbodily experience's impact can be enriching and devastating to the users' self-perception [5, 17].

2.2 Sense of Embodiment and Body Awareness

For the usage of VR and avatars in mind-body therapy, it is essential to investigate how the embodiment of avatars is related to our physical body awareness. Previous research on this encounter has led to mixed results. A person's body awareness trait can affect how susceptible they are to accept artificial body parts or virtual bodies [24, 50, 63, 68, 69] and how susceptible they are to be influenced in their interoceptive accuracy by congruent or incongruent stimulation [24]. These effects might result from an increased susceptibility to external stimuli in participants with low awareness of internal body signals. Studies on self-reported trait body awareness scales and SoE yielded mixed results [10, 13, 15]. However, a self-reported state of body awareness positively correlates to VBO and agency using personalized, photorealistic avatars [20]. Döllinger et al. [17] compared body awareness in VR to a real mirror exposure. In their study, VR negatively impacted self-reported body awareness, indicating a shift of attention toward visual processing. A sense of being physically changed by the avatar mediated this effect.

A majority of the studies on SoE and body awareness focus on the Rubber Hand Illusion [13, 24, 63] or faces presented as images and embodied via visuotactile stimulation [24]. Others use fully embodied generic-looking [15] or elaborately created photorealistic avatars [17, 20]. The results diverge accordingly. It has yet to be investigated systematically how the appearance of a full-body avatar impacts the relationship between SoE and body awareness.

2.3 The Impact of Avatar Appearance

Numerous studies have delved into the impact of avatar appearance on SoE. One example is the degree of anthropomorphism of the avatar. Mixed results have been observed so far. In earlier studies, the less human-looking or less realistic avatars increased VBO [35, 44, 46]. In later studies, this effect was inverted [40]. Besides a realistic human appearance of the avatars, the similarity between user and avatar contributes to a SoE. For instance, Jo et al. [35] found that individualizing avatars had a greater effect on VBO than increasing rendering realism. Similarly, Waltemate et al. [76] demonstrated that personalization positively affected VBO using photorealistic scanned avatars. In contrast, the degree of realism had no effect when comparing scanned to hand-modeled generic avatars. Salagean et al. [61] investigated the impact of personalization and photorealism using lower and higher photorealistic avatars. They found a significant in-VR effect on VBO, indicating a higher VBO for highly photorealistic, personalized avatars. Matching the results of former studies, they found an overall positive effect of photorealism and personalization on VBO. These results are consistent with two recent reviews. Weidner et al. [78] analyzed the effects of avatar and virtual body part appearance on different aspects of VR perception, especially the SoE. They found that the VBO benefits from a personalized avatar appearance, independently from the degree of realism. They concluded that generic realistic or personalized realistic full-body self-avatars could be promising but emphasized the need to explore varying realistic appearances. The results of Mottelsson et al. [52] support this conclusion. A systematic meta-analysis found that avatar individualization affected VBO and, to a limited degree, the sense of agency. However, they found these effects in only a limited number of papers. Accordingly, they, too, stress the importance of further investigation.

2.4 The Role of VR User Experience

In addition to investigating SoE, several avatar-related and non-avatar-related variables are open to debate in research on VR experiences. The most commonly mentioned VR UX variable is the SoP, which has been discussed, analyzed, and investigated for underlying perceptual mechanisms such as plausibility in various works [41, 66, 67]. In the area of avatar and agent evaluation, in addition to SoE, variables such as virtual human plausibility, i.e., the perception of the plausibility of the appearance and behavior of an avatar in VR, are discussed [45]. In addition, the uncanny valley effect is considered widely. It describes a feeling of eeriness towards realistic, human-like avatars [16]. This effect should be controlled for the usage of VR in a therapeutic setting and has been named as an exclusion criterion for the use of avatars [65]. To better understand the psychological mechanisms of VR in therapy, Wienrich et al. [79] suggest that any investigation of VR interventions should go beyond assessing the VR's effect on the respective behavioral or therapeutic outcome. They suggest considering moderator or mediator effects of VR UX variables and their association with therapeutically relevant psychological states. However, previous work on VR-induced health behaviors [59] or VR mind-body interventions [19] has rarely considered the relationship between intended behaviors or psychological states and VR UX. Regarding mind-body interventions, first experiments have investigated the relationship between SoE and body awareness. However, how body awareness behaves in relation to other VR UX measures remains open.

3 METHODS

3.1 Design

In a 3×1 study design, participants were randomly assigned to one of three conditions with different levels of avatar individualization (see Fig. 2). In the first condition, *generic*, participants embodied a generic, realistic-looking humanoid avatar. In the second condition, *customized*, the participants chose the appearance of their realistic-looking humanoid avatar using a custom avatar selection system (see Section 3.3.3). In the third condition, *personalized*, the participants embodied photorealistic scans of their real bodies. As dependent variables, we tested the participant's body awareness, interoceptive accuracy, and avatar-related and non-avatar-related measures of VR UX. The study was conducted according to the Declaration of Helsinki and approved by the ethics committee of the Institute Human-Computer-Media (MCM) of the University of Würzburg [1].

3.2 Participants

Ninety-four individuals participated in the study and received course credits or 15 EUR. We excluded individuals (1) with photosensitivity (e.g., due to epilepsy), (2) with severe uncompensated visual impairments, (3) with mobility difficulties, (4) when reporting symptoms of simulation sickness, or (5) with less than three years of experience with the German language. We included two control items asking to mark a specific rating. We excluded one participant due to not marking asked ratings. Further, we excluded three participants due to tracking/calibration errors and four due to errors in constructing the personalized avatar. A total of 86 participants remained. In the generic condition, $n = 29$, the mean age was $M = 23.10$ years ($SD = 3.88$), with 23 female and six male participants. Seventeen had < 5 hr, eight had $5 - 20$ hr, and four had > 20 hr of VR experience. In the customized condition, $n = 29$, the mean age was $M = 25.03$ years ($SD = 7.64$), with 19 female and ten male participants. Thirteen had < 5 hr, eight had $5 - 20$ hr, and seven had > 20 hr of VR experience. In the personalized condition, $n = 28$, the mean age was $M = 21.54$ years ($SD = 2.40$), with 23 female and five male participants. Twenty had < 5 hr, three had $5 - 20$ hr, and six had > 20 hr of VR experience.

3.3 Apparatus

The study was performed in a quiet laboratory at the University of Würzburg, Germany. It consisted of a small office room, where participants could answer questionnaires on a desktop computer using LimeSurvey 4 [42], and a bigger lab room for the VR exposition.

3.3.1 Technical System

The VR system consisted of a Valve Index Head-Mounted Display (HMD) [74] and two Valve Index controllers (Knuckles) tracked by three SteamVR Base Stations 2.0. The cable-bound HMD provided a resolution of 1440×1600 px per eye, a refresh rate of 144 Hz, and a total field of view of $109.4 \times 114.1°$ [80]. It was driven by a high-end gaming PC with an Intel Core i7-9700K, an Nvidia RTX2080 TI, and 32 GB RAM running Windows 10. The participants' fingers were tracked via the proximity sensors of the Knuckles. We did not include tracking of facial expressions. For body tracking, we used the markerless tracking system from Captury [8], employing eight FLIR Blackfly S BFS-PGE-16S2C RGB cameras attached to the laboratory ceiling to track participants' movements at a rate of 100 Hz. The cameras were connected to a powerful workstation composed of an Intel Core i7-9700K, an Nvidia RTX2080 TI, 32 GB RAM, and two 4-port 1 GBit/s ethernet frame-grabber running Ubuntu 18 and Captury Live (version 248). We captured the participant's heart rate using the Empatica E4 smartwatch [22] connected via Bluetooth to a Samsung Galaxy S6 smartphone for data logging. The VR experience was implemented using Unity (version 2020.3.25f1 LTS) [73] and integrated the VR system using SteamVR and its corresponding Unity plug-in (version 2.6.1)[2]. The body pose was continuously streamed to the VR system using a 1 GBit/s ethernet connection and integrated using Captury's Unity plug-in[3]. Subsequently, we always retargeted the received body pose to the currently used avatar. We merged it with the remaining tracking data from the VR system using Unity's avatar animation system and a custom-written retargeting script using the implementations utilized in our prior works [20, 21].

3.3.2 Virtual Environment

Participants were exposed to a virtual office adapted from a Unity asset[4] that included a couch, a desk, a mirror, and a large window showing a wood-inspired environment (see Fig. 1). Following the guidelines for mirror placement by Wolf et al. [80], the participants' position was determined by rendering a position marker on the floor at a distance of 1.5 m in front of the mirror. Left to the mirror, we added a whiteboard to display experimental instructions. The walls of the virtual room were aligned roughly according to the walls of the lab, creating an intuitive limit for the possible movement area.

3.3.3 Avatars

Generic For the generic condition, we created one female and one male avatar using the Autodesk Avatar Generator (version

[1] https://www.mcm.uni-wuerzburg.de/forschung/ethikkommission/

[2] https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647

[3] https://captury.com/resources/

[4] https://assetstore.unity.com/packages/3d/props/interior/manager-office-interior-107709

Figure 2: Generic (left), customized (center), and personalized (right) avatar of an exemplary participant.

1.0.693) [4]. We exported them as a quad mesh with high resolution for Unity. Fig. 2, left, shows the generic male avatar. The female version was designed accordingly.

Customized For the customized condition (Fig. 2, center), we chose six body characteristics and varied them systematically, resulting in 67 avatars created using the Autodesk Avatar Generator. The characteristics included a variation in gender (male and female), skin color (light-skinned and dark-skinned), body shape (low body fat, high body fat, and high muscle mass), clothing (black and white shirt), hair color (brown and blonde), and hair length (short and long). To allow user customization, we created an avatar selector as part of the LimeSurvey questionnaires. Step by step, participants were presented with a subset of the avatars and asked to select the avatar that best matched their appearance. The selection started with the gender and skin color of the avatar, moving on to the body shape and proceeding to the hair length, color, and clothing.

Personalized For the personalized condition, we created photorealistic avatars of our participants (see Fig. 1, right or Fig. 2, right) using the reconstruction pipeline presented by Achenbach et al. [1]. The generation process followed the procedure described by Bartl et al. [6] and involved capturing 94 simultaneous photos of the participants using a custom-built multi-DSLR camera setup. The photos were input for generating a dense point cloud representation of the participants' bodies using Agisoft Metashape [2]. The point cloud was the foundation for modifying a fully rigged template mesh sourced from the Autodesk Character Generator [4] based on statistical parameters and non-rigid deformation. Finally, we created the avatar's photorealistically personalized texture [6].

3.4 Measures

3.4.1 Body Awareness and Mindfulness

We assessed several aspects of body awareness using rating scales and performance measures. We assessed the participants' everyday life body awareness using the Multidimensional Assessment of Interoceptive Awareness - Version 2 (MAIA) [47] questionnaire. It comprises 37 items divided into eight scales: Noticing, Non-Distracting, Not-Worrying, Attention Regulation, Emotional Awareness, Self-Eegulation, Body Listening, and Trusting. It is measured on a 6-pt Likert scale ranging from 0 to 5.

We used the State Mindfulness Scale (SMS) [70] to assess body awareness post-VR. It consists of 21 items divided into two scales: state mindfulness of mind (SMS Mind, 15 items) and state mindfulness of body (SMS Body, 6 items). It is measured on a 5-pt Likert scale ranging from 1 to 5.

To assess body awareness in VR, we extracted items from several questionnaires matching the following aspects: Noticing External, Noticing Internal, Body Listening, Attention Regulation, and Visual Attention [17]. The items were adapted from the SMS, the State Mindfulness Scale - Physical Activity (SMS-PA) [12], and the Objectified Body Consciousness Scale (OBCS) [51]. To separate body awareness from mindfulness, we created three additional in-VR items for mindfulness, assessing the Noticing of Thoughts, the Noticing of Affect, and Thought Watching. All of these were extracted from the SMS [70]. The in-VR items were presented as 10-pt scales ranging from 1 to 10.

In addition, we assessed interoceptive accuracy via a heartbeat-counting task (HCT) [62] using the instructions presented by Desmedt et al. [14]. Participants sat on a chair while resting their arms on the armrest. We instructed them to count their heartbeats over a trial of 45 sec. We calculated an interoceptive accuracy score by dividing the absolute difference between counted and actual heartbeats by the actual heartbeats, resulting in a percentual score between 0 and 1, with higher numbers indicating higher interoceptive accuracy. As we had some technical issues during heartbeat tracking, the results on HCT are reduced to N = 77 participants (n = 27 generic, n = 27 customized, n = 23 personalized).

3.4.2 VR UX: Avatar Perception

Regarding avatar-related VR UX, we assessed the following variables: SoE, virtual human plausibility, and the uncanny valley effect.

We assessed SoE in VR and post VR using the Virtual Embodiment Questionnaire (VEQ) [60]. The VEQ assesses SoE on the three dimensions of perceived Body Ownership (BO), Agency (AG), and Change (CH), each with four items rated on a 7-pt Likert scale. For in-VR assessment, we selected one item from each dimension, inVR BO, inVR AG, and inVR CH, which loaded highest on it and adapted the scales to range from 1 to 10.

To assess virtual human plausibility, we used the Virtual Human Plausibility Scale (VHPS) [45]. The VHPS consists of 11 items presented as 7-pt Likert scales, ranging from 1 to 7. It includes two dimensions, virtual human Appearance and Behavior Plausibility (ABP) and virtual human Match to the Virtual Environment (MVE).

We used the Uncanny Valley Index (UVI) [33] to assess the uncanny valley effect. It comprises an affective appraisal of the avatar using 18 items divided into three dimensions, Humanness, Eeriness, and Attractiveness. It is measured on a 7-pt scale ranging from 1 to 7. Additionally, we included two in-VR items that matched the UVI: inVR Satisfaction and inVR Discomfort [17].

3.4.3 VR UX: Non-Avatar-Related Measures

Finally, we controlled non-avatar-related VR UX variables, SoP, and simulator sickness. To assess SoP, we used the in-VR One Item Presence Scale (OIPS) [7]. It consists of a single item, using a 10-pt scale ranging from 1 to 10. To capture simulator sickness, we included the Simulator Sickness Questionnaire (SSQ) [37]. It includes 16 items and three dimensions, Nausea, Oculomotor, and Disorientation. Items are assessed on a 5-pt scale ranging from 0 to 4. The total score ranges from 0 to 220.

3.5 Tasks and Procedure

3.5.1 Embodiment Tasks

To evoke an SoE, the participants performed movement tasks based on Waltemate et al. [76]. The exercises target different body parts and have a duration of about 20 s each, slightly differing by the length of the instruction. Guided by audio instructions, participants waved at their reflection, lifted their knees, and rotated their hips while raising their arms. The embodiment tasks lasted 3 min and 4 s.

3.5.2 Body Awareness Movement Tasks

The leading VR task consisted of standing movement tasks based on the Basic Body Awareness Therapy exercises [30]. These aim to evoke body awareness through repetitive, small-scale body movements. The instructions emphasized performing the movements slowly and attentively, focusing on sensing the body during the process. Following instructions for maintaining a stable and upright

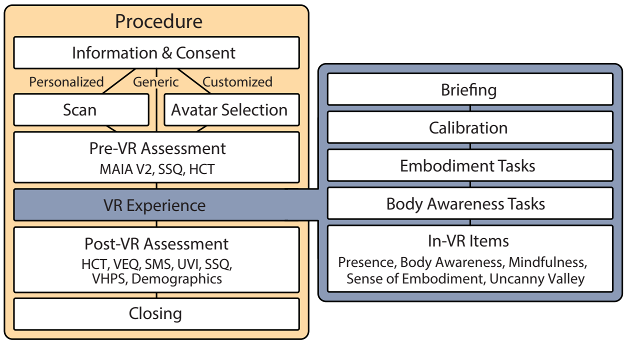

Figure 3: Overview of the experimental procedure.

stance, participants sequentially performed the exercises 'squat," "rotation," "wave," and "push" for durations ranging from 75 to 115 s each. The squat exercise involved a rocking motion of the legs accompanied by arm swinging. In the rotation exercise, participants rotated their torsos from left to right. The wave exercise comprised an up-and-down movement of the arms. Lastly, participants adopted a step position and executed a forward-pushing movement with their hands. After providing the initial instruction for a movement task, we instructed the participants to repeat the movement until the next instruction. The interval between instructions lasted 45 s. The body awareness movement tasks lasted 13 min and 19 s.

3.5.3 Procedure

Fig. 3 shows the whole experimental procedure. It consisted of three phases: pre-VR, in-VR, and post-VR. Pre-VR, all participants started by reading the study information and signing consent to participation and data processing. Participants in the customized conditions started customizing their avatar, while participants in the personalized condition underwent the body scan process. In the next step, all participants answered the MAIA and SSQ questionnaires and assessed their interoceptive accuracy via HCT.

In-VR, the participants received a short briefing and were introduced to the VR equipment and virtual environment. The VR experience followed a set sequence along with pre-recorded audio instructions. First, users tested their vision. We calibrated the body tracking system and adjusted the avatars' to the participants' body height. For calibration, participants had to perform a few idle movements and then stand motionless, looking straight ahead. In this phase, all instructions were additionally presented on the virtual whiteboard to ensure a rigorous execution and optimal calibration. Next, the whiteboard disappeared, and the avatar and a virtual mirror appeared. The participants were instructed to look at their avatar and perform the embodiment tasks in front of the mirror (see Sect. 3.5.1). The mirror disappeared, and participants performed the body awareness movement tasks (see Sect. 3.5.2). Finally, the virtual whiteboard reappeared. The in-VR items were presented visually and auditory. Participants were instructed to express the answer to each question aloud. To reduce social desirability bias, we emphasized that all answers were valid and no wrong answers could be given. Answering questions lasted about three minutes. The participants spent $M = 22.24$ $(SD = 0.96)$ min in VR. Post-VR, the participants performed the HCT a second time. Finally, they answered the VEQ, SMS, UVI, SSQ, VHPS, and demographic questions.

3.6 Hypotheses

Based on the related literature on body awareness, VBO, and agency, we expected higher ratings on these variables for higher levels of individualization. Further, we expected a reduced feeling of change and potentially increased eeriness ratings due to the increased similarity between user and avatar:

- H1.1: Higher individualization leads to increased SMS body and in-VR body awareness ratings.
- H1.2: Higher individualization leads to increased interoceptive accuracy.
- H2.1: Higher individualization leads to increased BO.
- H2.2: Higher individualization leads to increased AG.
- H2.3: Higher individualization leads to reduced CH.
- H2.4: Higher individualization leads to a higher UVI eeriness.

Further, we tested the following hypotheses concerning the relationship between SoE, VR UX, and body awareness:

- H3.1: Individualization affects the relationship between SoE and body awareness.
- H3.2: Individualization affects the relationship between avatar-related VR UX and body awareness.

Finally, we tested accordingly, on an exploratory basis, how the individualization of avatars affected non-avatar-related VR UX and mindfulness and how these were associated with body awareness.

4 Results

4.1 Analysis

All analyses were performed in R, using the R packages *jmv* and *stats*. Result plots were created using *ggplot2*. All models were tested against an alpha of .05. However, for a more precise insight and to account for the small sample size, post hoc analyses were also calculated for p-values $< .1$.

We calculated MANOVAs to test whether there were group differences in trait body awareness (MAIA). As multivariate normal distribution was not given, we report Wilks' Λ. To analyze the effects of avatar individualization (H.1 - H.2), we calculated ANCOVA and MANCOVA models for each variable, depending on the respective number of measures. To regard inter-individual differences in trait body awareness, we included the sub-dimensions of the MAIA questionnaire as covariates in these analyses. However, we retained to report only the results regarding our manipulation. For all significant MANCOVA models, we calculated post hoc ANCOVA models. For all significant ANCOVA models, we calculated post hoc t-tests. As effect sizes in the ANCOVA models, we calculated partial η^2. For post hoc t-tests, we calculated Cohen's d. For the post hoc t-tests, we report Bonferroni-Holm corrected p-values, p_{corr}.

To test for relations between SoE, VR UX, and body awareness (H3), we reduced the number of variables tested to the validated measures, including the SMS Body as the dependent variable and VEQ, UVI, and OIPS as potential predictors. For each predictor, we calculated a linear regression model, additionally including avatar individualization, to test for potential differences in slope between conditions. Again, we calculated partial η^2 as the effect size.

4.2 Demographics

All descriptive results are shown in Table 1. The MANOVA regarding MAIA ratings revealed no significant difference between the groups, $F(16,148) = 0.966, p = .497$.

4.3 Effects of Avatar Individualization

4.3.1 Body Awareness and Mindfulness

In line with H1.1, the MANCOVA model on body awareness, including the post-VR variable SMS Body and the in-VR body awareness ratings, revealed a significant effect, $\Lambda = 0.741, F(12,146) = 1.96, p = .049$. The univariate post hoc ANCOVA models revealed a significant effect on Noticing External, $F(2,75) =$

Table 1: Descriptive results of body awareness, SoE, and VR UX.

	Range	Generic M (SD)	Customized M (SD)	Personalized M (SD)
State Body Awareness				
SMS Body	[1 – 5]	3.72 (0.58)	3.68 (0.65)	3.37 (0.63)
Noticing External	[1 – 10]	4.96 (2.56)	4.69 (2.89)	3.14 (2.09)
Noticing Internal	[1 – 10]	7.68 (1.49)	7.48 (1.79)	7.25 (1.48)
Body Listening	[1 – 10]	7.54 (1.50)	6.31 (2.42)	6.71 (1.70)
Attention Regulation	[1 – 10]	8.07 (1.61)	7.24 (1.57)	7.64 (1.45)
Visual Attention	[1 – 10]	2.96 (1.71)	2.93 (1.91)	3.43 (1.55)
HCT (post - pre)	[0 – 1]	0.00 (0.13)	-0.02 (0.12)	0.04 (0.11)
Mindfulness				
SMS Mind	[1 – 5]	3.48 (0.61)	3.31 (0.65)	3.40 (0.76)
Noticing Thoughts	[1 – 10]	6.46 (2.46)	6.55 (2.64)	5.96 (2.28)
Noticing Affect	[1 – 10]	4.61 (2.22)	3.59 (2.10)	4.36 (2.23)
Thought Watching	[1 – 10]	4.61 (2.04)	4.41 (2.64)	5.25 (2.63)
Sense of Embodiment (SoE)				
VEQ BO	[1 – 7]	4.08 (1.45)	3.86 (1.51)	4.92 (1.28)
VEQ Agency	[1 – 7]	5.91 (0.76)	5.29 (1.25)	5.92 (0.95)
VEQ Change	[1 – 7]	2.34 (1.25)	2.75 (1.58)	2.85 (1.73)
inVR BO	[1 – 10]	5.36 (2.13)	4.38 (2.29)	6.43 (1.60)
inVR Agency	[1 – 10]	6.32 (1.91)	6.03 (1.88)	7.29 (1.82)
inVR Change	[1 – 10]	3.21 (2.41)	3.66 (2.47)	3.93 (2.39)
Virtual Human Plausibility				
MVE	[1 – 7]	5.84 (0.93)	5.57 (1.20)	5.84 (1.05)
ABP	[1 – 7]	5.56 (0.85)	5.39 (0.85)	5.64 (0.92)
Avatar Uncanniness				
UVI Humanness	[1 – 7]	3.16 (1.10)	3.13 (1.17)	3.74 (1.32)
UVI Attractiveness	[1 – 7]	4.68 (0.78)	4.54 (0.84)	4.45 (0.89)
UVI Eeriness	[1 – 7]	3.06 (0.71)	2.84 (0.67)	3.91 (0.65)
inVR Satisfaction	[1 – 10]	6.93 (1.98)	6.69 (1.89)	7.04 (1.90)
inVR Discomfort	[1 – 10]	2.57 (1.57)	3.00 (2.02)	2.86 (2.05)
Sense of Presence OIPS	[1 – 10]	6.89 (1.55)	6.86 (1.73)	6.43 (1.89)
Simulation Sickness				
SSQ Nausea	[-220 – 220]	-0.99 (26.42)	-8.22 (22.48)	-2.38 (22.73)
SSQ Oculomotor	[-220 – 220]	-3.66 (16.16)	-11.24 (19.50)	0.81 (19.17)
SSQ Disorientation	[-220 – 220]	0.96 (17.82)	-8.16 (23.97)	13.92 (36.93)

$4.60, p = .013, \eta^2 = .109$, and Body Listening, $F(2,75) = 3.39, p = .039, \eta^2 = .083$, but not on SMS Body, $F(2,75) = 3.03, p = .054, \eta^2 = .075$, Noticing Internal, $F(2,75) = 0.73, p = .484, \eta^2 = .019$, Attention Regulation, $F(2,75) = 1.89, p = .158, \eta^2 = .048$, or Visual Attention, $F(2,75) = 0.58, p = .561, \eta^2 = .015$.

Post hoc comparisons for SMS Body revealed a significant difference between generic and personalized avatars, $t(75) = 2.58, p_{corr} = .035, d = .715$, and between customized and personalized avatars, $t(75) = 2.52, p_{corr} = .035, d = .696$, but not between generic and customized avatars, $t(75) = 0.07, p_{corr} = .943, d = .019$, see Fig. 4, a. Accordingly, post hoc comparisons for Noticing External revealed a significant difference between generic and personalized avatars, $t(75) = 2.40, p_{corr} = .038, d = .665$, and between customized and personalized avatars, $t(75) = 2.77, p_{corr} = .021, d = .764$, but not between generic and customized avatars, $t(75) = 0.37, p_{corr} = .714, d = .099$, see Fig. 4, b. Post hoc comparisons for Body Listening did not reveal a significant difference between conditions after p-corrections, see Fig. 4, c.

Contrary to H1.2, an ANCOVA on post-HCT, including pre-HCT as a control, did not reveal a significant result, $F(2,66) = 1.90, p = .062$. An exploratory MANCOVA model on mindfulness, including the SMS Mind and the in-VR mindfulness variables, did not reveal a significant effect, $\Lambda = 0.849, F(8,144) = 1.54, p = .150$.

4.3.2 Sense of Embodiment

The MANCOVA model on SoE, including the VEQ dimensions and the in-VR SoE ratings (H.2.1 - H.2.3), revealed a significant effect, $\Lambda = 0.736, F(12,140) = 1.93, p = .035$. The univariate post hoc tests revealed a significant effect on VEQ BO, $F(2,75) = 3.67, p = .030, \eta^2 = .089$, and inVR BO, $F(2,75) = 6.45, p = .003, \eta^2 = .147$. It revealed a significant effect on VEQ AG, $F(2,75) = 3.67, p = .030, \eta^2 = .089$, but not inVR AG, $F(2,75) = 3.06, p = .053, \eta^2 = .075$. We found no significant effect on VEQ CH, $F(2,75) = 0.43, p = .654, \eta^2 = .011$, nor inVR CH, $F(2,75) = 0.27, p = .763, \eta^2 = .007$.

Post hoc comparisons for VEQ BO revealed no significant difference between generic and personalized avatars, $t(75) = 1.48, p_{corr} = .288, d = .407$, nor between customized and personalized avatars, $t(75) = 2.42, p_{corr} = .054, d = .670$, or generic and customized avatars, $t(75) = 0.97, p_{corr} = .334, d = .262$, see Fig. 4, d. Post hoc comparisons for inVR BO revealed a significant difference between customized and personalized avatars, $t(75) = 3.49, p_{corr} = .002, d = .967$, but not between generic and personalized avatars, $t(75) = 1.47, p_{corr} = .146, d = .406$, or generic and customized avatars, $t(75) = 2.08, p_{corr} = .082, d = .561$. Post hoc comparisons for VEQ AG revealed no significant difference between generic and personalized avatars, $t(75) = 0.33 p_{corr} = .741, d = .092$, nor between customized and personalized avatars, $t(75) = 1.99, p_{corr} = .101, d = .549$, or generic and customized avatars, $t(75) = 2.37, p_{corr} = .061, d = .641$, see Fig. 4, e. Post hoc comparisons for inVR AG revealed no significant difference between generic and personalized avatars, $t(75) = 1.34, p_{corr} = .362, d = .373$, nor between customized and personalized avatars, $t(75) = 1.96, p_{corr} = .160, d = .543$, or generic and customized avatars, $t(75) = 0.63, p_{corr} = .529, d = .171$.

4.3.3 VR UX: Avatar-Related Measures

In line with H2.4, a MANCOVA model on the uncanny valley effect, including UVI, and the in-VR items Satisfaction and Discomfort, revealed a significant effect, $\Lambda = 0.592, F(10,142) = 4.25, p < .001$. The univariate post hoc tests revealed a significant effect on UVI Eeriness, $F(2,75) = 19.74, p > .001, \eta^2 = .345$, but no significant effect on UVI Humanness, $F(2,75) = 1.89, p = 0.159, \eta^2 = .048$, UVI Attractiveness, $F(2,75) = 0.33, p = 0.716, \eta^2 = .009$, Satisfaction, $F(2,75) = 0.39, p = 0.680, \eta^2 = .010$, or Discomfort, $F(2,75) = 0.59, p = 0.557, \eta^2 = .015$. Post hoc comparisons for UVI Eeriness revealed a significant difference between generic and personalized avatars, $t(75) = 4.12, p_{corr} < .001, d = 1.14$, and between customized and personalized avatars, $t(75) = 5.10, p_{corr} < .001, d = 1.411$, but not between generic and customized avatars, $t(75) = 1.01, p_{corr} = .315, d = .273$, see Fig. 4, f.

A MANCOVA on virtual human plausibility, including the post-VR variables VHPS ABP and VHPS MVE, did not reveal a significant effect, $\Lambda = 0.980, F(4,148) = 0.38, p = .826$.

4.3.4 VR UX: Non-Avatar-Related Measures

An exploratory ANCOVA model on SoP, including the OIPS, revealed no significant effect, $F(2,75) = 0.71, p = .493$.

An exploratory MANOVA model on simulator sickness, including the post-VR variables SSQ Nausea, SSQ Oculomotor, and SSQ Disorientation, did not reveal a significant effect, $\Lambda = 0.880, F(6,146) = 1.60, p = .150$.

4.4 Avatar Appearance, VR UX, and Body Awareness

The regression models, including SoE measures, revealed a significant impact of VEQ BO on SMS Body, $F(1,80) = 4.62, p = .035, \eta^2 = .055$, but, contrary to H3.1, not a significant interaction, $F(2,80) = 0.36, p = .699, \eta^2 = .009$. They revealed a significant positive relationship between VEQ AG and body aware-

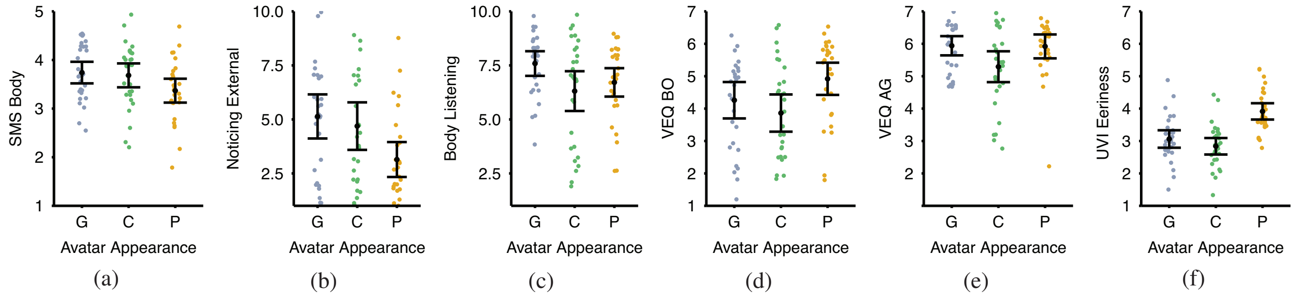

Figure 4: Effects of avatar individualization on body awareness and VR UX. The figure depicts the means, distributions, and standard errors. G = Generic, C = Customized, P = Personalized.

ness, $F(1,80) = 8.14, p = .006, \eta^2 = .092$, but no significant interaction, $F(2,80) = 0.74, p = .480, \eta^2 = .018$. Finally, they revealed neither a significant impact of VEQ CH on SMS Body, $F(1,80) = 0.05, p = .831, \eta^2 < .001$, nor a significant interaction, $F(2,80) = 1.22, p = .300, \eta^2 = .030$.

Contrary to our hypothesis H3.2, the regression model including UVI Eeriness revealed neither a significant impact of UVI Eeriness on SMS Body, $F(1,80) = 0.62, p = .433, \eta^2 = .008$, nor a significant interaction, $F(1,80) = 2.22, p = .116, \eta^2 = .053$. The regression model including UVI Humanness revealed neither a significant impact of UVI Humanness on SMS Body, $F(1,80) = 0.12, p_{corr.} = .727, \eta^2 = .002$, nor a significant interaction, $F(1,80) = 0.36, p = .697, \eta^2 = 009$. The regression model including UVI Attractiveness revealed neither a significant impact of UVI Attractiveness on SMS Body, $F(1,80) = 0.02, p = .889, \eta^2 < .001$, nor a significant interaction, $F(1,80) = 0.61, p = .545, \eta^2 = .015$.

A regression model including OIPS revealed a significant impact of OIPS on body awareness, $F(1,80) = 6.71, p = .011, \eta^2 = .077$, but no significant interaction, $F(2,80) = 0.31, p = .734, \eta^2 = .008$.

5 Discussion

Our findings demonstrate that the design of an avatar as a second perceivable body next to our physical body can impact body awareness in VR. Concerning our primary objectives, we came to the following conclusions: (1) Our results indicate that while the avatar customization hardly had any impact, the personalization negatively affected body awareness and partly affected avatar-related VR UX but not non-avatar-related VR UX. (2) Our study revealed a relationship between VR UX and body awareness, especially regarding the SoE and SoP. (3) The relationship between VR UX and body awareness did not differ between the levels of individualization. In the following, we discuss our results in depth.

5.1 Personalization Increases VBO and Eeriness

In our study, avatar individualization affected VR UX. Embodied personalized avatars led to significantly increased VBO (H2.1), persisting to some extent beyond the VR session. However, participants also experienced their personalized avatars as eerier than generic or customized ones (H2.4). These findings align with existing literature where similar personalization led to heightened VBO [35,44,61,76]. The link between personalization and eeriness aligns with the uncanny valley concept. However, it is worth noting that Salagean et al. [61] did not find this effect when comparing personalized to less personalized avatars. The feeling of agency (H2.2) appeared to differentiate between generic and customized avatars, but not significantly. This finding, too, aligns with previous literature indicating that manipulations of appearance have a stronger influence on VBO than on agency [52,61,78]. In addition, the overall lack of difference between generic and customized avatars could be explained by a deeper analysis of avatar preferences, as investigated by Fribourg et al. [26]. They found that a custom avatar chosen by participants to match their appearance was not necessarily preferred in terms of SoE and depended on the in-VR task. Another interesting observation is the absence of an effect on the VEQ Change (H2.3) [60]. This result suggests that the avatars' appearance, at least in our specific setting, does not alter the perception of one's physical body. However, VEQ Change was designed to evaluate applications in which the avatar is dissimilar to the user's appearance, creating a behavioral or experiential response. In this study, we aimed for a high similarity between the avatar and the user. Accordingly, our avatars might not have evoked a Change experience.

5.2 Body Awareness and VBO

The degree of avatar individualization significantly impacted self-reported body awareness ratings (H1.1) but not interoceptive accuracy (H1.2). Participants reported a significantly lower level of body awareness while embodying their personalized avatars, both during and after the VR experience, compared to embodying a generic or customized avatar. One explanation for this adverse effect of personalized avatars is a possibly increased cognitive load. A study by Mejia-Puig et al. [49] demonstrated that avatars inducing higher VBO also elevated cognitive load. Considering body awareness in the context of embodied cognition, increased cognitive load in VR could reduce the cognitive capacity available for processing internal bodily states. Since we did not measure cognitive load, it remains for future work to determine to what extent cognitive load contributes here and how it can be minimized. Regardless, our findings on the relationship between VBO, agency, SoP, and body awareness challenge this explanation. They indicate a positive relationship unaffected by the degree of individualization (H3.1, H3.2). These results align with related studies [15,17,20], contradicting the notion that increased VBO necessarily reduces body awareness. There seems to be an additional need for an explanation as to why personalized avatars reduce body awareness.

5.3 The Role of VR UX

Adhering to Wienrich et al.'s [79] guidelines, accounting for VR UX measures could bring further insights into the effect of avatar personalization on body awareness. In our study, next to an increased cognitive load, increased eeriness ratings could explain the effect of personalization on body awareness. Participants found their personalized avatars eerier than the other conditions, potentially triggering an uncanny valley response despite high VBO. This could have resulted in signals from the physical body being suppressed. However, we found no relationship between UVI and body awareness (H3.2), arguing against this explanation. Across conditions, eeriness did not negatively affect body awareness. Still, investigating in more detail whether controlling for eeriness mediates an effect of personalization on body awareness would be insightful.

A final explanation for the effect of personalization on body awareness could be a distraction by observing the details of the personalized avatar. For most participants, it was the first time embodying a personalized avatar. We aimed to minimize distraction by concealing the virtual mirror during body awareness exercises [17, 58], and participants did not report a preference for visuals over other signals. However, some participants still commented on the details of their personalized avatars. Further research is needed to gauge whether familiarity with a personalized avatar over multiple VR experiences mitigates their adverse effects on body awareness.

5.4 How Can We Find Balance?

The question arises to what extent the use of personalized avatars remains an option for therapeutic applications or to what extent a negative effect on body awareness can or needs to be avoided. In therapeutic settings, maximum personalization of avatars is not always possible, if only for financial reasons. But are personalized avatars a desirable goal if they reduce body awareness?

Defining the trade-off between avatar appearance and the possible consequences for body awareness and other critical psychological factors in therapy is crucial. Is a personalized avatar more likely to be perceived as a part of one's body, blurring the boundaries between the physical and the real body? Mind-body interventions often aim to direct attention to internal bodily signals [48]. Avoiding personalized avatars might be prudent given our body awareness and eeriness results. At least, determining which factors are decisive in avoiding undesirable reductions in body awareness induced by the avatar's appearance is essential. However, other therapeutic areas may build on a temporal reduction of body awareness. For example, an excessive fixation on the body as a symptom of a body image disorder could benefit from a temporal reduction of body awareness [21, 53]. In this context, it would be valuable to explore how a relationship between avatar appearance, VBO, and body awareness contributes to the success of such an application.

The VBO serves as a foundation for various VR phenomena that could be useful in VR mind-body interventions, such as the Proteus effect [45]. In our study, VBO positively predicted body awareness. Therefore, regardless of the type of avatar used, we deem it essential to strive for a strong sense of VBO within the appropriate range. To further explore the relationship between personalized avatars, VBO, body awareness, and the experience of eeriness, future studies could take inspiration from research investigating the effects of subtle differences in avatar appearance [61]. Understanding the dynamics between these constructs will contribute to developing more sophisticated guidance in avatar selection for therapeutic scenarios.

5.5 Limitations

Our results provide essential insights into the interaction of body and avatar perception. Regardless, our findings are limited. While we used avatars with similar realism, detailing, and anthropomorphism, our personalized avatars differed slightly from the other conditions. It has been indicated that the effects of personalization also arise when controlling for avatar creation and when using the same avatar type for personalized or generic avatars [76]. However, a study examining subtle differences in personalization and rendering realism could provide valuable insights into this matter [61].

In addition, it is crucial to discuss our choice of generic avatars. We chose avatars that could be interpreted as white, relatively thin, and young adults. In the customized condition, participants mainly chose avatars that resembled our generic avatars, only differing in hair color or muscle mass. We take this as an indicator that the generic avatars were well-suited for our particular sample. However, using these avatars in a more diverse sample could lead to considerable variance in the similarity between participants and avatars. Since our sample is limited, generalizability needs further investigation. Using generic avatars is always likely to result in a variance in similarity. Thus we recommend controlling for similarity, for example, by assessing perceived self-similarity or self-attribution as parts of self-identification [29], as proposed by Fiedler et al. [23].

Further, we are aware that the SMS Body, as part of a mindfulness questionnaire, and our in-VR items do not fully cover the construct of body awareness. So far, few measures refer to a subjective state of body awareness. There is a lack of valid measures to do justice to the dimensionality of body awareness while still referring to the current state of the participant rather than their trait body awareness. Gathering the participants' subjective responses to the VR experience could have given further insights into our data collection. Especially an inclusion of qualitative measures, such as post-experience interviews or the newly-introduced tool InwardVR by Haley et al. [31], could help gain more nuanced knowledge in future work.

Regarding the objective measures used in this study, the absence of an HCT effect can be attributed to several factors. It is worth discussing whether interoceptive accuracy, assessed via HCT, is valuable in the context of short-term effects. While it has been under debate as a tool in assessing body awareness [11], the HCT is often considered a moderately stable measure of interoceptive accuracy [72] with a relatively high inter-individual variance. Thus, to reveal potential short-term effects [24], testing with larger sample sizes and reducing variance by forming subsets seems necessary.

Finally, we have to discuss the therapeutic potential of our experiment. Body awareness is integral to mind-body interventions, and our body awareness movement tasks resemble standard therapeutic methods. However, we conducted our experiment with a non-clinical sample and did not use therapeutic framing. Our findings on the relationship between body awareness and VR UX are a necessary step in VR-oriented mind-body interventions. However, the study provides rather fundamental insights that can serve as a basis for a more clinical setting in future work.

6 Conclusion

Body awareness is a crucial determinant of the success of mind-body therapy approaches. Our study investigated the impact of avatar individualization and VR UX on body awareness in VR. In our work, customization of avatars had minimal influence, whereas personalization led to reduced body awareness, increased virtual body ownership (VBO), and an increased uncanny valley effect. Other VR UX measures, such as virtual human plausibility and simulation sickness, were not affected. Further, irrespective of the condition, our results revealed a significant relationship between the VBO and sense of presence (SoP) and body awareness.

These results demonstrate the importance of examining both VR UX measures and the relationship between VR UX and body awareness in a therapeutic context. In our study, personalization, while causing a high VBO, reduced body awareness even though we found a generally positive relationship between the two variables. This result highlights that the relationship between VR UX and body awareness is not always straightforward. Even designs that seem obvious at first glance might lead to undesirable outcomes that would be overlooked if not controlled for. Future research should clarify the complex interplay between personalization, VBO, eeriness, and body awareness. Understanding these interrelationships can inform the design and development of VR interventions, especially in therapeutic contexts, where the manipulation of avatar appearance and VR UX might influence targeted outcomes.

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