Are Embodied Avatars Harmful to our Self-Experience? The Impact of Virtual Embodiment on Body Awareness

Nina Döllinger
Psychology of Intelligent Interactive Systems at University of Würzburg
Würzburg, Germany
nina.doellinger@uni-wuerzburg.de

Erik Wolf
Human-Computer Interaction Group at University of Würzburg
Würzburg, Germany
erik.wolf@uni-wuerzburg.de

Mario Botsch
Computer Graphics Group at TU Dortmund University
Dortmund, Germany
mario.botsch@tu-dortmund.de

Marc Erich Latoschik
Human-Computer Interaction Group at University of Würzburg
Würzburg, Germany
marc.latoschik@uni-wuerzburg.de

Carolin Wienrich
Psychology of Intelligent Interactive Systems at University of Würzburg
Würzburg, Germany
carolin.wienrich@uni-wuerzburg.de

Figure 1: A participant in front of a mirror: the virtual replicas (left) were designed to match the real setting (right).

ABSTRACT

Virtual Reality (VR) allows us to replace our visible body with a virtual self-representation (avatar) and to explore its effects on our body perception. While the feeling of owning and controlling a virtual body is widely researched, how VR affects the awareness of internal body signals (body awareness) remains open. Forty participants performed moving meditation tasks in reality and VR, either facing their mirror image or not. Both the virtual environment and avatars photorealistically matched their real counterparts. We found a negative effect of VR on body awareness, mediated by feeling embodied in and changed by the avatar. Further, we revealed a negative effect of a mirror on body awareness. Our results indicate that assessing body awareness should be essential in evaluating VR designs and avatar embodiment aiming at mental health, as even a scenario as close to reality as possible can distract users from their internal body signals.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *Laboratory experiments*; *Empirical studies in HCI*.

KEYWORDS

Sense of embodiment, virtual reality, interoception, body ownership, agency, body perception, virtual humans

ACM Reference Format:
Nina Döllinger, Erik Wolf, Mario Botsch, Marc Erich Latoschik, and Carolin Wienrich. 2023. Are Embodied Avatars Harmful to our Self-Experience? The Impact of Virtual Embodiment on Body Awareness. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23), April 23–28, 2023, Hamburg, Germany*. ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3544548.3580918

CHI '23, April 23–28, 2023, Hamburg, Germany

ACM ISBN 978-1-4503-9421-5/23/04.
https://doi.org/10.1145/3544548.3580918

1 INTRODUCTION

Every living being on our planet has a body. Our bodies enable us to interact with our environment while continuously providing information about that environment, our movements and posture, our internal states, and our subjective well-being. A core research question of cognitive science deals with the perception of our body. Embodiment, the experience of simultaneously being and having a body [71], depicts a research perspective that defines the body as a prerequisite for mental processes and examines them concerning their bodily foundation and expression. The body is consequently defined as an elementary component of human experience and self-perception [72]. Recent discussions on VR, avatars, and the metaverse raise an additional question: What happens to our bodily experience when we suddenly have to act and interact through a digital replica instead of our well-known and familiar body?

VR can replace a person's physical body with an arbitrary virtual self-representation (virtual body or avatar) that can be controlled and used to interact with a virtual environment. Through virtual bodies, or rather the discrepancy between the virtual and the physical body, it is possible to manipulate various aspects of body perception. For example, being represented by thinner or larger virtual bodies can alter the perception of body size [48, 50, 76], extended or misaligned arms and legs to an altered estimation of one's reaching distance [37], or increased latency to an altered perception of one's body weight [33]. Inspired by early experiments on bodily illusions, especially the Rubber Hand Illusion (RHI) [8], a substantial fraction of VR research deals with the question of what it means to have a body, how it feels to possess or embody it – and to what extent a virtual body is perceived as a part, extension, or substitute of the physical body. The term embodiment extends thereby from having and controlling a physical to a virtual body. It is often operationalized as a sense of embodiment (SoE), or the "conscious experience of self-identification (body ownership), controlling one's body movements (agency) and being located at the position of one's body in [a virtual] environment (self-location)" [52, p. 3547].

One aspect of body perception of particular interest in embodiment research is body awareness, the ability to recognize subtle internal body signals [45]. Body awareness is a core element of our self-perception. It is related to psychological and physical well-being and affects the management of chronic medical conditions such as chronic pain [24], eating disorders [35], or anxiety and depression [49]. Therefore, the application of VR in various areas of life raises the question of the extent to which the embodiment of virtual bodies poses not only a chance but a risk to our body awareness. Is the replacement of our own body with a virtual body disturbing? Or can it even support body awareness by drawing attention to the body through external stimulation? The embodiment of artificial body parts has been shown to interact with body awareness. Filippetti and Tsakiris [19] found that the RHI can positively affect body awareness, but identification with an unfamiliar face leads to a reverse effect. Döllinger et al. [15] discovered a positive correlation between SoE toward a personalized virtual body and body awareness. However, it has not been investigated systematically to what extent the embodiment of a virtual body affects body awareness compared to interactions with one's physical body. Further, there has been no research on the effect of the confrontation with one's (virtual) mirror image, a common tool in the embodiment of virtual bodies [32], on body awareness.

In a 2x2 mixed design study with 40 participants, we investigated how embodying a photorealistic virtual body affects body awareness compared to interacting with one's physical body. Participants performed a series of body-based movement exercises in a real and virtual laboratory. While they viewed, controlled, and explored their physical bodies in the real environment, they embodied a photorealistic personalized virtual body in VR. During the experience, they were either confronted with an additional third-person perspective on their body via a (virtual) mirror or not. We recorded their self-reported body awareness, SoE, and performance in a heartbeat counting task as dependent variables. In doing so, we investigate the extent to which the two factors, virtuality and perspective, affect body awareness and the role of the SoE within these effects. Our work empirically connects body awareness and SoE in VR and compares how the sense of embodiment toward virtual bodies differs from that toward real bodies. Our results allow us to infer for VR design whether even a VR scenario that is as close to reality as possible can distract users from their physical bodies. In addition, they challenge the role of a mirror in the design of VR-based embodiment and (mental) health scenarios.

2 RELATED WORK

2.1 Body Awareness in Mind-Body Therapy

Our body constantly gathers, processes, and filters information about our environment. It is sensitive to the outside temperature, the intensity of touch, or the noise of our surroundings. In addition to external signals from our environment, signals from inside the body maintain our self-awareness [63]. The processing of these internal body signals, especially the interoceptive and proprioceptive signals, is called body awareness. It is defined as the "subjective, phenomenological aspect of proprioception and interoception that enters conscious awareness and is modifiable by mental processes such as attention, interpretation, evaluation, beliefs, memories, conditioning, attitudes, and affect" [45, p. 4]. Therefore, body awareness is a central part of perceiving the body's sensations and includes the perception of various internal body signals, such as hunger and heart activity or other more complex perceptive syndromes. It is often captured via self-reports or operationalized as interoceptive accuracy (IAC) and assessed via heartbeat-counting tasks.

Body awareness is closely linked to mental health and subjective well-being [28] and is negatively related to symptoms of depression [49], eating disorders [35], or migraine [55]. On the other hand, body awareness dysfunctions are associated with increased suicidal thoughts and actions [30]. Following these findings, Gibson [25] proposed in a recent discussion that a strengthened IAC or body awareness accounts for the benefits of mindfulness practice in different research. The processing of the body's internal signals has become the focus of several therapeutic approaches, so-called mind-body therapies, aiming to integrate mind and body awareness into daily life via breathing, meditation, or movement exercises [46]. Although the practical application of body awareness in therapy varies widely, in a qualitative study on the definition of body awareness in therapy, Mehling et al. [46] found a great deal of commonality in understanding body awareness among practitioners. Therapists have defined body awareness in two ways, as a core element of integrity and an essential part of self-awareness and as an individual's capacity and ability for embodiment.

Therapeutic approaches aiming to increase or adapt body awareness mostly rely on modifying body awareness via attention regulation. Directing attention to external body signals can facilitate the processing of interoception [3, 42]. Especially in the field of mindfulness, some developments and design ideas have been proposed to integrate VR into mind-body therapy approaches. In this context, VR allows arbitrarily adapting the visible environment or augmenting feedback to body movements or physiological measures using virtual stimuli. While research in this area has predominantly relied on mindfulness, the influence of virtual bodies on body awareness could provide new insights into the mechanisms of body awareness and embodiment and how virtual stimuli could help maintain or manipulate body awareness in a virtual therapy scenario [4, 14].

2.2 Embodying Virtual Bodies

VR experiences rely on supplementing, modifying, or replacing a particular part of body signals with virtual stimuli. Typically, this is done by displaying visual stimuli while excluding visual information from the real environment. Adapting visual movements to the user's actions establishes a state of congruence between the digital (visual) and non-digital (proprioceptive, vestibular, and kinesthetic) stimuli [39]. Upon meeting this state, the virtual experience is perceived as plausible and thus elicits a sense of presence. When embodying a virtual body, the congruence of a virtual body's behavior and look can lead to plausibility [43] and a perceptual shift towards the virtual body. Kilteni et al. [36, p. 375] define this state as the Sense of Embodiment (SoE), "the sense that emerges when [the body's] properties are processed as if they were the properties of one's own biological body". In the context of our work, the question arises whether one's body perception is influenced when the visual body signals do not come from the own body. Through bottom-up processing of congruent visuotactile or visuomotor stimulation, the perception of a virtual body is integrated into one's physical body perception causing the virtual body to be perceived as a part, extension, or substitute of the physical body. A typical method to enhance the SoE towards a virtual body is the mirror metaphor [32]. By adding a mirror to the virtual environment and consciously juxtaposing the user with their virtual mirror image, the effect of visuomotor or visuotactile congruence is intended to be reinforced [57].

2.3 The Impact of Avatar Embodiment on Body Perception

In VR, external and internal body signals may be overridden or suppressed by the external signals presented through the embodiment of virtual bodies. For example, in a study on temperature sensitivity in the palm, Llobera et al. [41] showed that external temperature stimuli are processed less dominant during the embodiment of a virtual body. In their study, half of the participants were presented with a visuomotor congruent virtual body whose movements and posture corresponded to their own. In contrast, the other half of the participants were presented with an incongruent representation. It turned out that participants in the congruent condition were less sensitive to temperature differences. The authors stated a distraction by the visual stimuli could not explain this effect but an integration of the congruent virtual body into the own body perception. Concerning the processing of internal body stimuli, Kasahara et al. [33] showed in a study on visuomotor congruence that delays in the body movement of a virtual body produced a feeling of heaviness in one's physical body. In contrast, faster virtual body movements produced a feeling of physical lightness. In addition to the visuomotor congruence between the physical and the virtual body, it has been investigated to what extent an inconsistency between dimensions of body parts impacts body perception, for example, proprioception and the perception of one's body position and dimensions. Van der Veer et al. [68] demonstrated that the positioning of virtual body parts relative to the physical body might lead to a proprioceptive shift when estimating the position of physical body parts. Kilteni et al. [37] showed that the length of virtual arms influences the perception of one's own reach and body space. With remark to an embodiment scenario with virtual bodies, various works demonstrated that embodying virtual bodies of different sizes impacts body weight perception and the estimation of one's body size [48, 50, 76].

However, it remains unclear whether these influences on the different aspects of body perception are equivalent to an impact on body awareness. When considering the goal of mind-body interventions, strengthening the connection between body and mind, the question arises of whether VR can be a suitable tool for mental health interventions. Suppose body perception is affected by those external stimuli. Does the embodiment of virtual bodies and the associated distraction from the real body towards a virtual body have a disruptive effect on body awareness?

2.4 The Relationship between Body Awareness and Sense of Embodiment

2.4.1 Body Awareness Affects the Sense of Embodiment. Working with artificial bodies is integral for exploring body awareness and embodiment, as it allows us to manipulate and investigate what it means to feel, own, or control a body. Consequently, literature on this topic initially addresses how body awareness, or IAC, affects the adoption of SoE towards artificial or virtual bodies or body parts, mainly using the Rubber Hand Illusion as a tool of exteroceptive manipulation. In this method, visuotactile congruent stimulation and simultaneous visual occlusion of the physical hand produce an SoE toward an artificial hand. Tsakiris et al. [63] discovered a negative relation between IAC and accepting such external stimuli. Based on the RHI, they investigated to what extent the individual IAC affected the SoE towards the artificial hand. They found that the RHI affected individuals with low IAC more than individuals with high IAC. The authors concluded that the influence of external stimuli is more substantial when the individual processes fewer interoceptive signals. In an experiment on body awareness, IAC, and the autism spectrum, Schauder et al. [54] replicated the results of Tsakiris et al. [63]. Again, IAC negatively affected the SoE towards a rubber hand, supporting the proposed trade-off between internal and external cue processing. While the two previous experiments focused on the embodiment of generic hand models, Tajadura-Jiménez and Tsakiris [61] investigated the influence of IAC on SoE towards an unfamiliar face in a so-called enfacement illusion. In their study, individuals with low IAC were more likely to be influenced by the interaction with the face and to show more SoE towards this face than individuals with low IAC. The influence of self-reported body awareness on susceptibility to the RHI has also been investigated, but no impact was found [10]. In an embodiment scenario with virtual bodies in VR, Dewez et al. [13] further investigated how self-reported body awareness influences SoE towards a generic virtual body. They found a descriptive but no significant relationship between body awareness and SoE, similar to the relationship between IAC and SoE.

2.4.2 Embodiment of Virtual Bodies Affects Body Awareness. In addition to the studies on the impact of body awareness and IAC on SoE, a few investigated the reverse research question of how the embodiment of an artificial body affects body awareness. Filippetti and Tsakiris [19] investigated the extent to which visuotactile congruence and a resulting variation in SoE affected body awareness using the RHI. They found that congruence of visual and tactile stimulation positively affected SoE and body awareness. Participants performed better in an IAC task after a high congruence condition than after a low congruence condition. A pre-post comparison revealed an increase in performance in the IAC task, but only for participants with a lower IAC at baseline. Thus, individuals with initially lower accuracy in detecting internal bodily sensations seem to benefit from the exteroceptive body signals of a congruent RHI task. In addition, Filippetti and Tsakiris [19] report an adverse effect of visuotactile congruence in an enfacement task when using the participant's face but not when using a generic face. When embodying a picture of their own face, individuals in the congruent condition achieved lower performance in IAC than individuals in the incongruent conditions. Overall, the enfacement illusion had a negative main effect on IAC for participants with higher IAC at baseline. This result contrasts with the results on the RHI. It indicates that including mirror exposure in the embodiment of artificial bodies might lead to different effects on body awareness than when the face of the artificial body is not visible. In the context of VR, Döllinger et al. [15] tested whether the SoE towards a photorealistically personalized virtual body was related to self-reported body awareness or IAC. They found a positive relationship between SoE and self-reported body awareness but not between SoE and IAC.

2.5 Summary and Contribution

The processing of exteroceptive signals from the RHI or embodiment of virtual bodies might partially compete with the processing of internal body signals and thus limit body awareness [54, 63]. The presented research highlights the importance of visuotactile or visuomotor congruence in the embodiment of artificial bodies or body parts to maintain or even strengthen body awareness. However, especially when embodying artificial faces, visuotactile congruence does not rule out a negative influence on body awareness [19]. During enfacement illusions, congruence might even have an adverse effect. In summary, prior work suggests a relationship between IAC and SoE and between self-reported body awareness and SoE. However, research is still pending on how VR affects body awareness and IAC compared to reality. It further needs to be investigated to what extent the presented perspective on a personalized virtual body affects the perceived body awareness and IAC.

To address these research gaps, we present a study investigating the effects of having a mirror image in a body awareness movement task in VR. Additionally, we investigate to what extent the embodiment of a highly personalized, photorealistic virtual body affects body awareness and IAC. In a 2×2 design, we evaluated the effects of virtuality and perspective on body awareness. Our participants performed movement exercises from Basic Body Awareness Therapy [27] either in a laboratory of the University of Würzburg or in a virtual model of that laboratory in VR in counterbalanced order (virtuality). When in VR, they embodied a virtual replica of themselves. Half of our participants performed the exercises in front of a mirror, and the second half performed them without a mirror (perspective). As dependent variables, we recorded their self-reported body awareness and SoE, measured in experience directly following the performed exercises. Additionally, we assessed their self-reported body awareness, SoE, and IAC measured after leaving the virtual or real laboratory environment. The results of our study intend to provide new insights into the effects of VR on body awareness and, thus, new insights into the relationship between one's virtual and physical body. Based on the work presented above, we hypothesize the following:

- H1.1: The SoE of an individual towards their virtual body in VR differs from the SoE towards their physical body in a real-world environment.
- H1.2: An additional visual perspective on the body, provided by a mirror, has a supporting effect on the SoE.
- H2.1: Even when embodying a photorealistic personalized virtual body, VR affects body awareness.
- H2.2: An additional visual perspective on the body, provided by a mirror, affects body awareness through exteroceptive stimulation.
- H3: The SoE towards a (virtual) body mediates the effects of perspective or virtuality on body awareness.

3 METHODS

3.1 Ethics

We conducted our study according to the Declaration of Helsinki and received approval from the ethics committee of the Institute Human-Computer-Media (MCM) of the University of Würzburg [1]. Given the prolonged exposure to the mirror image, we referred participants during acquisition and after the study to the freely available support services from the Anorexia Nervosa and Associated Disorders organization (ANAD) [2], which they could contact in case they felt uncomfortable about their body shape. Participants were informed in advance about the risks of VR regarding simulation sickness and epilepsy symptoms according to the local VR-usage guidelines. Before entering VR, participants were instructed to report any discomfort they felt during the VR experience immediately. In addition, we set up an area where participants could sit down in silence, hydrate, or lie down if needed.

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

3.2 Participants

A total of 45 students and employees of the University of Würzburg participated in our study and received either course credit or 30 EUR in return. Ahead of the evaluation, we defined four exclusion criteria queried by self-disclosure. Participants were not eligible when they (1) had visual impairments not compensated by contact lenses, (2) currently suffered from a diagnosed eating or body image disorder, (3) had less than three years of experience with the German language, or (4) reported simulation sickness symptoms during the experiment. We excluded one participant due to their visual impairment and four participants due to technical issues during the VR session ($n = 3$) or heart rate tracking ($n = 1$). Thus, we included 40 participants (25 female, 15 male) in our analysis. The participants were between 19 and 53 years ($M = 22.00$, $SD = 1.48$). Twenty-nine participants had spent less than 5 hours, seven participants had spent 5-10 hours, and 4 participants had spent 10-20 hours in VR. Six participants had never used a VR system before their participation.

3.3 Study Design

Our study was designed in a 2×2 mixed design with the two independent variables *virtuality* and *perspective*. The first independent variable, virtuality, included two experimental conditions performed by each participant: *reality* and *VR*. In reality, the tasks were performed in the local laboratory, while in VR, they were performed in a virtual replica of the local laboratory. The order of the two conditions was counterbalanced. The second independent variable, perspective, varied between participants. Participants performed the tasks described in Section 3.6.1 either *in front of a (virtual) mirror* or *without a mirror*. Thus, participants only received additional external cues about their bodies in the mirror condition. As dependent variables, we assessed the participants' self-reported body awareness and their IAC. As a possible mediator between the independent and dependent variables, we assessed their SoE towards their visible body. As control variables, we captured the participants' body awareness, body consciousness, and IAC prior to our experimental tasks and the two VR-related measures of simulator sickness and avatar uncanniness.

3.4 Apparatus

3.4.1 Hard- and Software. The VR hardware was integrated using SteamVR version 1.16.10 [67] and the corresponding Unity plugin version 2.7.3 [3]. The VR conditions were implemented using Unity 2020.3.11f1 LTS [65]. For calculating the avatar's general body pose, we used the Unity plugin FinalIK version 2.0 [4] in conjunction with the system architecture introduced by Wolf et al. [74].

Our VR setup consisted of an HTC Vive Pro HMD, two handheld Valve Index Controllers (Knuckles), and three HTC Vive Trackers 3.0. One tracker was attached to the hip and one to each foot. All devices were tracked using four SteamVR Base Stations 2.0. The HMD provided participants a total field of view of $108.8 \times 111.4\,^{\circ}$ and a resolution of 1440×1600 px per eye [5]. It ran at a refresh rate of 90 Hz. The participants' finger poses were tracked by the built-in proximity sensors of the Knuckles, while facial expressions were not tracked. The setup was driven by a high-end VR-capable workstation that consisted of an Intel Core i7-9700K CPU, an NVIDIA GeForce RTX 2080 Ti, and 32 GB RAM. To answer the questionnaires outside of VR, participants used an office workstation with a keyboard, mouse, and 24-inch LCD screen. The questionnaires were presented with LimeSurvey 4 [40]. For heart rate measures, we used the Empatica E4 smartwatch [17].

We determined our system's motion-to-photon latency by frame-counting [29, 58, 60]. For this purpose, the video signal output of the graphics card was split into two signals using an Aten VanCryst VS192 display port splitter, one of the signals led to the HMD and the other to an ASUS ROG SWIFT PG43UQ low-latency gaming monitor. The user's movements and the corresponding reactions on the monitor screen were captured using a Casio EX-ZR200 high-speed camera recording at 240 fps. The latency was repeatedly determined (n= 20) by counting the recorded frames between the user's movements and the virtual body's reaction while showing the virtual mirror and was, on average, 64.79 ms ($SD = 8.05$).

3.4.2 Real Environment. The study was performed in a laboratory of the University of Würzburg. In the room's center, a marker on the floor defined the participants' positions during different tasks. Following the guidelines for mirror placement of Wolf et al. [73], a mirror was placed at a distance of 1.5 meters from the participant. Depending on the perspective condition and the task, the mirror either showed the participants' reflection or was turned away. Two speakers stood on the floor next to the mirror to play audio instructions. Two desks were placed on one side of the room next to each other. One contained the questionnaire workstation for the participants. The other contained the VR workstation. To avoid participants' answers being affected by the experimenter's presence, a privacy screen separated the experimenter's workstation from the participants' workstation. Additionally, two privacy screens were placed between the experimenter and the participants during conditions. Thus, the participants could not see the experimenter while performing tasks.

3.4.3 Virtual Environment. We followed Skarbez et al. [56] and provided a virtual environment replicating the real laboratory (see Figure 1) to control environmental influences between the VR and reality conditions. The virtual environment was spatially aligned to the real environment by a custom calibration script. Hence, the position of the marker and the mirror matched in both environments.

3.4.4 Virtual Body. To provide a high similarity between the participants' real and virtual bodies, we used the method for fast generation of photorealistically personalized virtual bodies proposed by Achenbach et al. [1]. Using a custom-built multi-DSLR camera setup, 96 photos of the participants are taken simultaneously. The photos provide the input for generating a dense point cloud of the participants using Agisoft Metashape [2]. It serves as the basis for modifying a fully rigged template mesh originally taken from the Autodesk Character Generator [5] following statistical parameters and non-rigid deformation to accurately replicate the participants' body shape. In a further step, a photorealistic texture is generated that represents the personalized surface of the body. A more detailed explanation of the whole procedure can be found in Bartl et al. [7]. The virtual body was imported into Unity using an FBX-based

[3] https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647
[4] https://assetstore.unity.com/packages/tools/animation/final-ik-14290
[5] https://github.com/PeterTh/ovr_rawprojection

Table 1: In-experience items for SoE, body awareness, and avatar uncanniness.

Variable	Item	Original scale
Sense of Embodiment		
Body Ownership (BO)	It felt like the virtual body was my body.	VEQ [52]
Agency (AG)	The virtual body's movements felt like they were my movements.	VEQ [52]
Change CH	I felt like the form or appearance of my own body had changed.	VEQ [52]
Body Awareness		
Noticing external (NE)	I noticed various sensations caused by my surroundings (e. g. heat, coolness, the wind on my face)	SMS [62]
Noticing internal (NI)	I clearly physically felt what was going on in my body	SMS [62]
Body listening (BL)	I listened to what my body was telling me.	SMS-PA [9]
Attention regulation (AR)	It was easy for me to pay attention to my body.	—
Visual attention (VA)	I focused more on how my body looked than how it felt.	OBCS [47]
Avatar Uncanniness		
Satisfaction	I was satisfied with my body.	—
Discomfort	I felt uncomfortable in my body.	—

custom importer and animated in real-time according to the participants' movements using the hard- and software setup described above. To this end, we used the embodiment system presented by Wolf et al. [74] and evaluated by Döllinger et al. [16].

3.5 Measures

3.5.1 Sense of Embodiment (SoE). We assessed SoE both in experience and post experience using the Virtual Embodiment Questionnaire (VEQ) [52]. The VEQ measures 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 the in-experience assessment, we selected one item from each dimension, which loaded highest on it, and adapted the scales to range from 1 to 10. As we presented no virtual body in the reality condition, we adapted the wording of the items from "virtual body" to "visible body" for both assessments to match all of our conditions.

3.5.2 Self-Reported Body Awareness. We assessed self-reported body awareness ratings both in-experience and post-experience. For in-experience measurement, we extracted items from several questionnaires matching the following aspects of body awareness: noticing external cues (NE), noticing internal cues (NI), body listening (BL), attention regulation (AR), and visual attention (VA). The items were adapted from the State Mindfulness Scale (SMS) [62], the State Mindfulness Scale - Physical Activity (SMS-PA) [9], and the Objectified Body Consciousness Scale (OBCS) [47]. The extracted items, including sources, are presented in Table 1.

3.5.3 Interoceptive Accuracy (IAC). In addition to self-reported body awareness, we assessed IAC via a heartbeat-counting task [53]. Participants were instructed to sit calmly on a chair while resting their arms on the chair's armrest. They were asked to count their heartbeats over a trial of 45 sec but not guess if they did not feel any. To create an IAC score, we calculated the difference between their counting result and their actual heart rate during the time span relative to their actual heart rate.

3.5.4 Control Variables. To control potentially interfering factors, we additionally assessed the participants' everyday life body awareness using the Multidimensional Assessment of Interoceptive Awareness - Version 2 (MAIA) [44] questionnaire. It comprises 32 items divided into eight scales: noticing, non-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body listening, and trusting. It is measured on a 6-pt Likert scale ranging from 0 to 5. Additionally, we assessed the participants' everyday life body consciousness using the Objectified Body Consciousness Scale (OBCS) [47]. It comprises 16 items divided into two dimensions: body surveillance and body shame. It is measured on a 7-pt Likert scale ranging from 1 to 7. Finally, we controlled the VR-related variables simulator sickness and avatar uncanniness. To capture potentially occurring simulator sickness caused by latency jitter or other sources [59, 60], we included the Simulator Sickness Questionnaire (SSQ) [34]. It comprises 16 items, each querying a different symptom of simulator sickness, on a 4-pt scale ranging from 0 to 4. The total score ranges from 0 to 235.62. For avatar uncanniness, we assessed the Uncanny Valley Index (UVI) [31]. It comprises 18 items divided into four dimensions, humanness, eeriness, spine-tingling, and attractiveness. It is measured on a 7-pt scale ranging from 1 to 7. Additionally, we added two in-experience items for avatar uncanniness presented in Table 1.

3.6 Tasks

3.6.1 Body Awareness Movement Tasks. In both VR and reality, participants performed a series of movement exercises based on the Basic Body Awareness Therapy exercises from Gyllensten et al. [27]. These movement exercises usually aim to increase body awareness through small, repetitive body movements. The instructions focus on performing the movements slowly and deliberately while sensing the body. For our study, we selected only standing movement exercises. Following instructions for a stable, upright stance, participants performed the exercises "squat," "rotation," "wave," and "push" after each other for 75 to 115 seconds. For squat, participants performed a rocking motion of the legs to which they swung their arms. For rotation, they performed a rotation of the body around its longitudinal axis. Wave involved an up-and-down movement of the arms. For push, the subjects stood in step position and performed a forward press movement of the hands. For a more detailed description of each task, we refer to the work of Gyllensten et al. [27]. After the initial instruction of a movement task, we added the instruction to repeat the movement until the next exercise was presented. The pause between two instructions lasted 45 sec.

3.6.2 Mirror Exposure Task. Participants additionally performed a mirror exposure task. It established further exposure to the virtual body to test whether a confrontation with a virtual body in comparison to the physical body influenced body awareness. The mirror was turned around for the two conditions without a mirror to allow subjects to look at themselves for the first time during the study. In the other two conditions, the environment was not changed. Participants were instructed to stand centrally in front of the mirror and look at their mirror image for 3 min.

3.7 Procedure

The whole procedure of the study is illustrated in Figure 2. It was split into four phases: Preparation, reality condition, VR condition, and Closure. Both experimental conditions were presented in counterbalanced order and were executed with or without a mirror.

3.7.1 Preparation. During preparation, participants received information about the local COVID-19 regulation and the study procedure. They consented to the body scan and study participation and generated two personal pseudonymization codes to store their body scan and study data separately. Participants were then asked to take off their shoes. In the next step, the experimenter measured the participants' body height and performed the body scan described in Section 3.4.4. After the body scan, participants answered the pre-questionnaires, including their demographics, prior VR experience, and the MAIA, OBCS, and SSQ questionnaires. After answering the questionnaires, they performed the IAC task.

3.7.2 Reality Condition. In the reality condition, the participants were led to the center of the laboratory. Here, they performed the body awareness movement tasks described in Section 3.6.1. They then verbally answered the in-experience questions about body awareness, SoE, and avatar uncanniness. The mirror exposure task described in Section 3.6.2 followed. The instructions for both tasks were presented via pre-recorded audio instructions. The reality experience took $M = 18.26$ min ($SD = 1.71$). After the mirror exposure, the participants returned to the questionnaire workstation.

3.7.3 VR Condition. In preparation for the VR condition, the participants put on the tracking equipment described in Section 3.4.1. After introducing the virtual environment, participants were instructed to read a short sentence to test their vision within the virtual environment. The calibration of the virtual body followed. The participants were instructed to stand in a T-pose with their arms stretched to the sides. The instructions for the vision test and the calibration were presented verbally and in writing. A whiteboard to the left of the mirror displayed the written instructions. After calibration, the reality condition was performed analogously to the VR condition. The VR experience took $M = 19.88$ min (SD =1.86). After the last exercise, the participants put down the VR equipment and returned to the questionnaire workstation.

After each condition, the participants again performed the IAC task. Afterward, they answered the questionnaires SMS and VEQ. After the VR condition, they additionally answered the SSQ. At the end of the experiment, participants answered the UVI. In total, the study took $M = 118.38$ min ($SD = 19.19$).

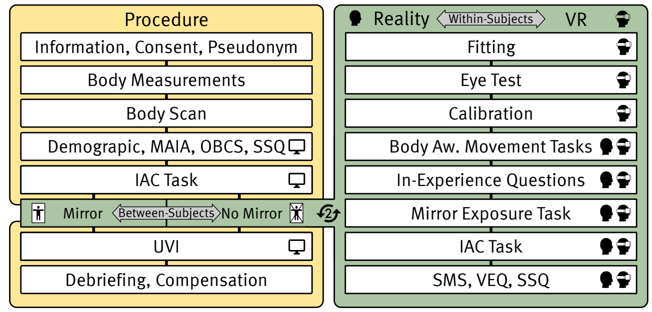

Figure 2: Overview of the experimental procedure (left) and of the repeated part of the exposure phase (right). The icons on each step's right side show the environment in which the step was conducted. The icon in the center indicates the repetition of steps.

4 RESULTS

4.1 Analysis

4.1.1 Effects of Virtuality and Perspective. We performed the entire analysis using R data analysis software. To analyze whether the virtuality or the perspective influenced the recorded measures of SoE and body awareness (H1.1, H1.2, H2.1, H2.2), we calculated 2×2 MANOVA models for the in-experience and 2×1 MANOVA models for the post-experience recorded measures of SoE and body awareness. For this purpose, we used the modified ANOVA-type statistic (MATS) for multivariate data proposed by Friedrich et al. [20], which is also applicable for repeated measures data. We applied the bootstrap approach proposed by Friedrich and Pauly [22] to avoid bias due to asymptotic distributions. To compute the model, we used the R package *MANOVA.RM* [21]. For the bootstrap, we applied 1000 iterations, each with parametric resampling. MANOVA models were interpreted at an alpha of .05.

For post-hoc comparisons after significant main effects, we directed 1×2 ANOVA models when only one main effect was significant or 2×2 ANOVA models when two main effects were significant. To account for small effects, we did not adjust the alpha value here. We calculated generalized η^2 (ges) as effect sizes.

4.1.2 Bayesian Multilayer Mediation. To analyze the extent to which the SoE towards the visible body mediated body awareness (H3), we considered the variables significantly affected by one of the two factors. We calculated a Bayesian multilayer mediation for each corresponding variable„ a multilevel modeling approach presented by Vuorre and Bolger [69], using their R package *bmlm.r*. Bayesian multilayer meditation takes non-independent observations from repeated measures into account and estimates regression models based on Markov Chain Monte Carlo (MCMC) procedures. These estimate individual-level and group-level parameters simultaneously. We used 2000 iterations for the sampling procedure. We report the means of the models' posterior distribution (Bayesian posterior distribution) and associated confidence intervals as estimates. In the results, we report the mediator models that showed a significant indirect effect based on confidence intervals and the respective direct effects.

4.1.3 Exploratory Analysis. In an additional exploratory analysis, we tested to what extent the participants found the encounter with their virtual bodies pleasant. For the in-experience measures of virtual body uncanniness, we calculated a 2×2 mixed design ANOVA model each. Again, we tested against an alpha level of .05.

4.2 Control Variables

4.2.1 Sample. Table 2 shows the results of all control variables for both the mirror and the no mirror group. To ensure that the two groups did not differ in their body awareness, we examined whether the MAIA was answered differently in the groups and whether performance in the IAC task differed.

4.2.2 General Effects of VR and Embodiment. We investigated the avatar's overall rating using the UVI. As shown in Table 2, the avatars were rated similarly between the mirror and no mirror condition on all dimensions. We found significant effects of virtuality on in-experience ratings of the visible body. Participants were more satisfied with their visible body in reality ($M = 7.97, SD = 1.70$) than in VR ($M = 6.30, SD = 2.21$), $F(1, 38) = 23.620, p < .001, ges = .157$. Additionally, participants felt more uncomfortable in their visible body in VR ($M = 3.17, SD = 2.24$) than in reality ($M = 2.30, SD = 1.47$), $F(1, 38) = 5.729, p = .022, ges = .052$. We found no significant effects of perspective on in-experience ratings of the visible body, neither for satisfaction, $F(1, 38) = 0.509, p = .480, ges = .009$, or for discomfort, $F(1, 38) = 0.131, p = .719, ges = .002$.

In a pre-post comparison of the SSQ scores, we tested whether participants had to be excluded due to simulator sickness. Results showed a maximum pre-post difference of 26.18 ($Md = -3.74, M = -7.67, SD = 19.75$) and a maximum post-measure of 104.72 ($Md = 18.70, M = 26.55, SD = 25.01$). As the participant with the highest increase in SSQ scores was not an outlier in the other scores and the two participants who scored maximum in post-measures reported only a small increase (11.22) or a decrease (−11.22) in SSQ scores, we referred from excluding participants due to simulation sickness.

Table 2: Descriptive results of all control variables divided between groups.

	Range	Mirror M (SD)	No mirror M (SD)
Body Awareness			
MAIA Attention regulation	[0 – 5]	4.11 (0.60)	4.21 (0.73)
MAIA Body listening	[0 – 5]	3.47 (1.05)	3.80 (0.79)
MAIA Emotional awareness	[0 – 5]	4.49 (0.94)	4.79 (0.67)
MAIA Self regulation	[0 – 5]	3.80 (1.01)	3.99 (0.79)
MAIA Non-distracting	[0 – 5]	1.03 (0.91)	0.92 (0.65)
MAIA Noticing	[0 – 5]	4.59 (0.77)	4.78 (0.51)
MAIA Not-worrying	[0 – 5]	2.44 (0.73)	2.29 (0.72)
MAIA Trusting	[0 – 5]	4.98 (0.85)	4.93 (0.86)
Interoceptive accuracy	[0 – 1]	0.65 (0.19)	0.66 (0.20)
Body Consciousness			
OBCS Body surveillance	[1 – 7]	3.79(0.50)	4.11 (0.64)
OBCS Body shame	[1 – 7]	3.00 (0.46)	2.69 (0.65)
Simulation Sickness	[0 – 220]	30.35 (4.12)	32.9 (5.25)
Avatar Uncanniness			
UVI Humanness	[1 – 7]	4.24 (1.40)	3.83 (1.25)
UVI Attractiveness	[1 – 7]	4.76 (1.00)	4.31 (1.19)
UVI Eeriness	[1 – 7]	4.11 (0.85)	4.45 (1.19)
UVI Spine-tingling	[1 – 7]	4.30 (0.83)	4.13 (0.87)
In-experience Satisfaction	[1 – 10]	6.95 (2.33)	7.32 (1.93)
In-experience Discomfort	[1 – 10]	2.83 (1.92)	2.65 (1.97)

4.3 Main Effects of Virtuality and Perspective

4.3.1 Sense of Embodiment. Table 3 shows the descriptive results of our dependent variables divided between the four conditions. In line with H1.1, our MANOVA model revealed a significant main effect of virtuality on SoE, $MATS = 120.623, p < .001$. Contrary to H1.2, it did neither reveal a significant main effect of the perspective on SoE, $MATS = 2.111, p = .521$, nor a significant interaction between virtuality and perspective, $MATS = 2.640, p = .416$. The post-hoc t-tests on virtuality revealed that when measured in-experience, perceived body ownership towards the visible body in reality was higher than in VR, $t(39) = 9.13, p < .001, d = 1.44$. Perceived agency towards the visible body was higher in reality than in VR, $t(39) = 7.80, p < .001, d = 1.23$. Perceived change of the physical body experience via the visible body was lower in reality than in VR, $t(39) = -2.93, p = .003, d = -0.46$. The result is depicted in Figure 3, left.

Confirming H1.1, when measured post-experience, our MANOVA model revealed a significant effect of virtuality on SoE, $MATS = 34.169, p < .001$. The post-hoc t-tests revealed when measured post-experience, perceived body ownership towards the visible body was higher in reality than in VR, $t(39) = 4.093, p < .001, d = 0.65$, perceived agency towards the visible body was higher in reality than in VR, $t(39) = 4.29, p < .001, ges = .679$. Perceived change of the physical body experience via the visible body was significantly higher in VR than in reality, $t(39) = -2.03, p = .025, d = -0.32$.

4.3.2 Body Awareness. When measured in-experience, in line with H2.1 and H2.2, our MANOVA model revealed a significant main effect of virtuality on body awareness ratings, $MATS = 14.174, p = 0.031$ and of the perspective on body awareness ratings, $MATS = 27.606, p = .002$. We did not find a significant interaction between virtuality and perspective, $MATS = 3.665, p = .577$. The post-hoc ANOVA models revealed some main effects of virtuality. When measured in-experience, noticing internal, $F(1, 38) = 7.485, p = .009, ges = .055$, attention regulation, $F(1, 38) = 4.662, p = .037, ges = .044$, and visual attention, $F(1, 38) = 4.763, p = .035, ges = .052$, were rated higher in reality than in VR, see Figure 3, right. For noticing external, $F(1, 38) = 2.22, p = .144, ges = .011$, and body listening, $F(1, 38) = 0.169, p = .683, ges = .002$, we did not find a significant impact of virtuality.

Similarly, post-hoc ANOVA models revealed some main effects for perspective. When measured in-experience, participants rated their visual attention higher when a mirror was available than when no mirror was available, $F(1, 38) = 24.255, p < .001, ges = .264$. We did not find a significant effect of the perspective on either noticing external, $F(1, 38) = 0.070, p = .793, ges = .001$, noticing internal, $F(1, 38) = 0.064, p = .802, ges = .001$, body listening, $F(1, 38) = 0.085, p = .773, ges = .002$, or attention regulation, $F(1, 38) = 0.051, p = .823, ges < .001$. Contrary to H2.1, we did not find a significant effect of virtuality on SMS Body ratings or IAC performance, $MATS = 1.737, p = .42$.

Table 3: Descriptive results of all variables compared between conditions.

		VR		Reality	
		Mirror	No mirror	Mirror	No mirror
	Range	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Sense of Embodiment (SoE)					
VEQ BO	[1 – 7]	4.82 (1.85)	4.65 (1.55)	6.26 (1.27)	5.95 (1.41)
VEQ Agency	[1 – 7]	5.76 (0.85)	5.66 (0.99)	6.61 (0.92)	6.36 (0.88)
VEQ Change	[1 – 7]	2.84 (1.70)	3.34 (1.48)	2.25 (1.28)	2.67 (1.72)
In-exp. BO	[1 – 10]	5.65 (2.56)	5.3 (2.30)	9.45 (1.32)	8.60 (1.76)
In-exp. Agency	[1 – 10]	6.00 (2.10)	6.4 (2.19)	9.60 (1.10)	8.75 (1.74)
In-exp. Change	[1 – 10]	5.30 (2.85)	5.4 (2.09)	3.55 (3.00)	3.80 (2.97)
Body Awareness					
SMS Body	[1 – 75]	3.67 (0.64)	3.60 (0.68)	3.82 (0.57)	3.67 (0.62)
Noticing External	[1 – 10]	4.55 (2.50)	4.00 (2.20)	4.65 (2.23)	4.85 (2.37)
Noticing Internal	[1 – 10]	7.10 (2.00)	7.35 (1.18)	8.15 (1.23)	7.70 (1.42)
Body Listening	[1 – 10]	6.70 (1.75)	6.90 (1.55)	7.15 (1.18)	7.20 (1.54)
Attention Regulation	[1 – 10]	6.80 (1.96)	7.25 (2.12)	8.10 (1.29)	7.45 (1.64)
Seeing vs. Feeling	[1 – 10]	6.40 (2.35)	3.70 (2.23)	5.25 (2.27)	2.85 (1.87)
Interoceptive Accuracy	[0 – 1]	0.66 (0.18)	0.69 (0.16)	0.70 (0.20)	0.73 (0.15)

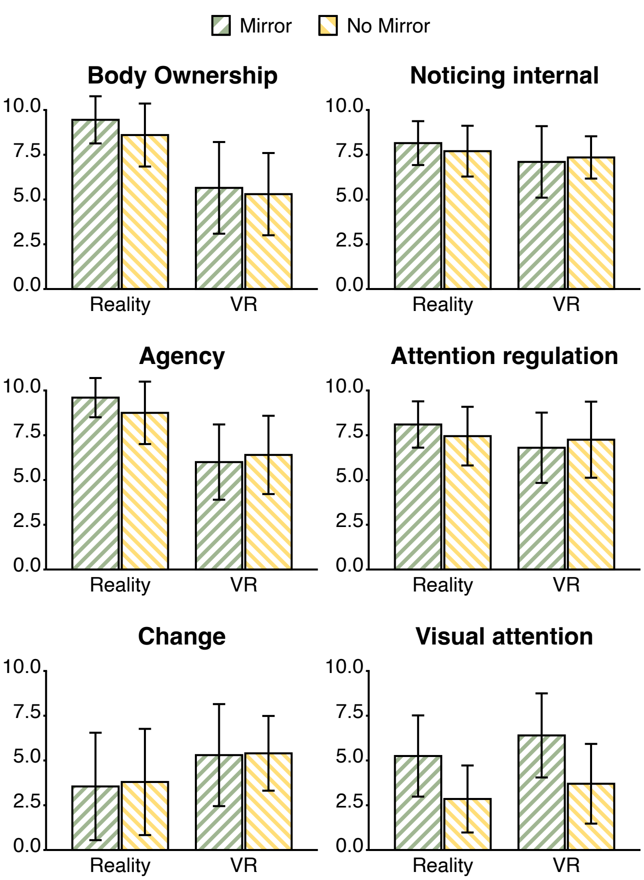

Figure 3: Means and standard deviations of body ownership, agency, and change (left) and noticing internal, attention regulation, and visual attention (right) in our conditions.

4.4 Mediator Analysis

Based on our main effects, we calculated a mediation analyses on virtuality as the independent variable, the three dimensions of SoE as mediator, and the body awareness ratings noticing internal, attention regulation, and visual attention as dependent variable.

4.4.1 Body Ownership. We tested whether body ownership mediated the effects between virtuality and in-experience body awareness ratings. We did not find a significant indirect effect between virtuality and body awareness through body ownership for noticing internal, $M_{posterior} = -0.14, SD = 0.19, CI = [-0.55, 0.18]$, attention regulation, $M_{posterior} = -0.13, SD = 0.15, CI = [-0.47, 0.12]$ or visual attention, $M_{posterior} = 0.06, SD = 0.13, CI = [-0.21, 0.35]$.

4.4.2 Agency. We tested whether agency served as a mediator between virtuality and body awareness ratings. We found no significant indirect effect between virtuality and body awareness through body ownership for noticing internal, $M_{posterior} = -0.18, SD = 0.16, CI = [-0.54, 0.09]$, or visual attention, $M_{posterior} = 0.08, SD = 0.13, CI = [-0.16, 0.38]$. However, we showed a significant indirect effect between virtuality and attention regulation through body ownership, $M_{posterior} = -0.26, SD = 0.17, CI = [-0.64, 0.00]$ (see Figure 4, left). As shown, virtuality predicted attention regulation (total effect), $M_{posterior} = -2.98, SD = 0.39, CI = [-3.72, -2.22]$, with users rating their attention regulation lower in VR than in reality. This effect was attenuated when controlling for agency (path c'), $M_{posterior} = -2.72, SD = 0.58, CI = [-3.45, -1.96]$. Virtuality further predicted agency (path a), $M_{posterior} = -0.76, SD = 0.63, CI = [-1.45, -0.08]$, with higher ratings of agency in reality than in VR. The feeling of agency was related to attention regulation (path b), $M_{posterior} = 0.34, SD = 0.06, CI = [0.06, 0.62]$.

4.4.3 Change. Finally, we tested whether change served as a mediator between virtuality and body awareness ratings. We encountered a significant indirect effect between virtuality and noticing internal through change, $M_{posterior} = 0.53, SD = 0.30, CI =$

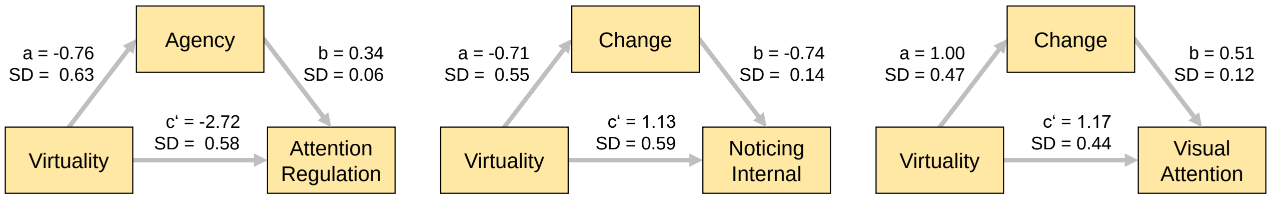

Figure 4: The left figure depicts the relative effect of virtuality on attention regulation and the two direct effects of virtuality on agency and of agency on attention regulation. The center figure depicts the relative effect of virtuality on noticing internal and the two direct effects of virtuality on change and of change on noticing internal. The right figure depicts the relative effect of virtuality on visual attention and the two direct effects of virtuality on change and of change on virtual attention.

[0.06, 1.20], as depicted in Figure 4, center. As shown above, virtuality predicted noticing internal (total effect), $M_{posterior} = 1.66, SD = 0.56, CI = [0.59, 2.83]$, with users rating their noticing internal higher in VR than in reality. This effect was attenuated when controlling for change (path c'), $M_{posterior} = 1.13, SD = 0.59, CI = [0.04, 2.29]$. Again, as shown above, virtuality predicted change (path a), $M_{posterior} = -0.71, SD = 0.55, CI = [-1.21, -0.20]$, with higher ratings of change in VR than in reality. Additionally, the feeling of change was related to noticing internal (path b), $M_{posterior} = -0.74, SD = 0.14, CI = [-1.33, -0.13]$. Additionally, we found a significant indirect effect between virtuality and visual attention through change, $M_{posterior} = 0.51, SD = 0.29, CI = [0.02, 1.16]$, as depicted in Figure 4, right. As shown above, virtuality predicted visual attention (total effect), $M_{posterior} = 1.68, SD = 0.60, CI = [0.49, 2.83]$, with users rating their feeling higher in reality than in VR. This effect was attenuated when controlling for change (path c'), $M_{posterior} = 1.17, SD = 0.44, CI = [0.06, 2.24]$. Again, as shown above, virtuality predicted change, (path a), $M_{posterior} = 1.00, SD = 0.47, CI = [0.05, 1.95]$, with higher ratings of change in VR than in reality. Additionally, the feeling of change was related to visual attention (path b), $M_{posterior} = 0.51, SD = 0.12, CI = [0.23, 0.79]$. We did not find a significant indirect effect between virtuality and body awareness through change for attention regulation, $M_{posterior} = 0.51, SE = 0.29, CI = [0.02, 1.16]$.

5 DISCUSSION

In this paper, we presented a laboratory study on the effects of virtuality, perspective, and SoE on body awareness. We manipulated the degree of virtuality between plain reality and immersive VR to test whether self-reported body awareness and IAC during and after a body awareness task get affected. Additionally, we tested the effects of the visual perspective on the (virtual) body, operationalized via the presence or absence of a mirror. Mirrors provide a third-person perspective on the own body and are often used to enhance the SoE towards virtual bodies in VR. In contrast, body awareness tasks usually do not include mirror exposure. When answered in-experience, we found a significant negative effect of virtuality on body awareness ratings for noticing internal and attention regulation and a positive effect on visual attention. Further, we found a significant positive effect of the perspective on visual attention. Participants focused more on what they saw than what they felt when a mirror was present. In our study, feeling agency over a body and being changed by exposure to it mediated the effect of virtuality on body awareness. While agency partly explained the impact on attention regulation, change partly explained the effect on noticing internal and visual attention. However, these effects did not last until after the experience, as we did not find a significant impact of virtuality on either SMS ratings or heartbeat-counting performance (IAC). In the following, we discuss how these results answer whether the embodiment of virtual bodies is an opportunity or a threat to body awareness and virtual approaches to mind-body therapy.

5.1 Are Effects of a Mirror Perspective on Body Ownership a Myth?

As expected (H1.1), we found a significant effect of virtuality on the SoE. Both in-experience and post-experience, participants reported feeling more body ownership and agency towards their physical body in the real environment than towards their virtual body in VR. Additionally, they stated that they experienced more change in their bodily experience in VR than in reality. The ratings in the reality condition were generally very high for body ownership and agency. When assuming that all perception and cognition are body-based [72], the feeling of owning and controlling our physical body should be at a maximum at all times. However, some participants still rated their body ownership and agency in the reality condition lower than the maximum score and stated a feeling of change, although they did not have to split their body ownership between two competing bodies in this condition. There can be various reasons for this. There are certain states in which people do not feel embodied in their physical body or able to control it, such as depersonalization or derealization. The mere question of body ownership or agency may elicit a questioning of one's bodily state. Similar to the sense of presence in VR compared to reality [66], it seems to be possible that people generally do not report full SoE in reality. To what extent this should impact the interpretation of SoE ratings in virtual reality remains open for future work.

Contrary to our expectations (H1.2), our participants did not report different SoE when confronted with their mirror image than without it. Similar to our results, two recent studies investigated the effects of mirrors on the SoE. Wolf et al. [73] stepwise increased the distance to the third-person perspective provided by a virtual mirror from two to eight meters and could not find any sign of a declining SoE. Bartl et al. [6] investigated the effects of virtual bodies in VR-based physical exercises and did not find an effect of placing a virtual mirror in front of the participants. Past research shows that confrontation with (virtual) mirrors – while being used and proposed as a tool to reinforce SoE [11, 38, 57, 75] – has not yet been investigated extensively until recently. Studies on the impact of a third-person perspective on SoE often rely on a perspective where the participants see their virtual body only from behind, compared to an egocentric first-person perspective [11, 12, 26]. Apparently, both via first-person or third-person perspective, a certain amount of SoE can be achieved via visuomotor or visuotactile congruence. However, depending on the tracking accuracy, the first-person perspective, or alternating between both, lead to higher body ownership and agency than the third-person perspective [11].

Regarding our study, there are three possible explanations for the lack of perspective effects. First, our sample size was relatively small, and minor effects such as those visible in the descriptive data could have been detected with a larger sample. Second, our participants had potentially high expectations concerning the appearance and movements of their virtual bodies. To our knowledge, no research exists on the expectations of VR users toward their personalized virtual bodies. Thus, while Waltemate et al. [70] found a positive effect of personalization on SoE, minor deviations in facial features could have impacted the SoE in our study, especially as we did not contrast the personalized virtual bodies with generic virtual bodies. Future work should investigate whether the embodiment of generic or less realistic virtual bodies leads to similar results concerning the existence of a virtual mirror. Third, despite considerable technological progress, the embodiment of virtual bodies still does not work flawlessly. Contrary to the beneficial effect of mirrors in a virtual embodiment lab proposed by Spanlang et al. [57], in a study on the effect of mirrors on SoE, Rey et al. [51] found higher ratings in SoE in conditions without a mirror than in conditions with a mirror. They explained this effect based on the properties of the mirror they used. Inoue and Kitazaki [32] propose that SoE decreases during exposure to a virtual mirror image when the virtual body does not move synchronously. In our study, we used a low-threshold embodiment system with six-point tracking where the pose between points was calculated approximately. Thus, minor deviations in the posture of arms and legs and missing facial animations could have gradually reduced SoE over time. Consequently, more accurate tracking could be necessary to hold up SoE for such tasks. For future work, we recommend showing a mirror image only for a short introduction to the virtual body, if at all, to avoid possible disturbances caused by minor tracking deviations.

5.2 Virtuality Affects Body Awareness – Are Virtual Bodies Worth Considering in the Design of Mind-Body Therapy?

Using a realistic scenario and photorealistically personalized virtual bodies, we found some effects of virtuality on body awareness (H2.1) that did not last over the experience. During the experience, our participants found it significantly more challenging to focus on their bodies, reported noticing fewer signals from within their bodies, and relied more on what they saw than what they felt in VR than in reality. Filippetti and Tsakiris [19] reported a positive effect of the RHI on body awareness, operationalized as IAC. We could not extend this result to virtual bodies in our study, as we did not find an effect of virtuality on IAC. Our effects on self-reported body awareness indicate a negative impact of virtuality.

Since we did not work with generic body parts in our setup but with personalized virtual bodies, our results are more comparable to the second experiment of Filippetti and Tsakiris [19]. They showed that prolonged confrontation with images of one’s face in an enfacement illusion could harm IAC. While IAC and self-reported body awareness are discussed as independent concepts [18], our results on self-reported body awareness indicate a similar effect of the confrontation with photorealistically personalized virtual bodies on body awareness. Still, we did not find an effect of virtuality on IAC. In our study, the use of a mirror without additional haptic stimulation or the inclusion of facial animations had close to no effect. This result contradicts the hypothesis that the confrontation with one’s face would be a causal factor in differences in body awareness (H2.2). While participants reported that they paid more attention to their visuals than to their other bodily sensations, they did not report reduced body awareness in the other measures. Future work could investigate how the personalization of virtual bodies contributes to the found effects. In previous work, personalization has affected SoE positively [70] and IAC negatively [19]. However, the extent to which it affects body awareness when embodying a virtual body has not yet been investigated. In addition, future work should address to what extent not only latency but posture accuracy and tracking performance [23] affect body awareness. Previous studies mainly focused on the effects of visuotactile congruence, while no transfer to virtual bodies and visuomotor congruence has been performed yet. It may be concluded that virtuality, at least for our realistic scenario, had neither a lasting supportive nor a disruptive effect on body awareness. Further, providing a mirror to supposedly strengthen the SoE did not affect body awareness negatively. To ensure that the focus during a virtual mind-body exercise remains on the body’s sensations, and as the positive effect of prolonged mirror exposure on SoE is questionable, we would still argue against using a mirror during the whole length of virtual exercises.

Future research will bring further insights into how virtual body design can support users in maintaining body awareness. Although we found only a partial impact of VR on body awareness, caution should be exercised when using virtual bodies in VR-based mind-body exercises. When creating such scenarios, designers should consider how the VR environment, the performed task, and the virtual body itself affect body awareness. For example, if a mirror is task-immanent, designers should identify solutions to draw attention back to internal body signals. When an avatar is used to guide the user, its appearance and behavior should aim to draw attention to the body while avoiding visual distractions. Depending on the intended outcome, designers should carefully consider to what extent a distraction from internal body signals is likely to happen, problematic, or even desirable.

5.3 SoE Mediates the Effects of Virtuality on Body Awareness

Based on the work of Filippetti and Tsakiris [19] and Döllinger et al. [15], we expected that a manipulation of the SoE would mediate the perceived body awareness in our tasks (H3). Our results partly confirmed this assumption as we found significant mediating effects of SoE on each of the variables that were affected by virtuality. We found a significant partial mediating effect of perceived agency on attention regulation and a significant partial mediating effect of perceived change on noticing internal and visual attention. While a higher agency was associated with a higher attention regulation, higher change ratings were associated with less noticing internal and more attention to visual signals. However, we did not find mediating effects for the effect of perspective on body awareness. The result is consistent with Döllinger et al. [15], who found a positive correlation between body ownership and agency and body awareness (assessed via SMS). However, it extends the findings as we could show that not only was SoE related to body awareness ratings but also explained part of the effects of virtuality on body awareness. The negative correlation between change and noticing internal is particularly interesting. When embodying virtual bodies, we are confronted with potentially contradicting signals about our bodies. If these lead us to perceive our body as changed, the visual signals seem to have more influence than the internal signals. This result thus fits well with the assumptions of research on individual differences in SoE towards a rubber hand or virtual body [13, 54, 63, 64]. It supports the hypothesis that external and internal stimuli compete in such scenarios. While prior work focused on individual capacity to process external signals, we showed that, at least in the short term, increased processing of external stimuli appears to be associated with reduced processing of internal stimuli.

5.4 Limitations

In addition to the limitations already mentioned above, such as the sample size or possible tracking imprecision, we would like to mention a few limitations of our study design. Our results are limited to virtual experiences where the virtual environment and the virtual body of the participants strongly resemble reality. In developing the virtual environment, we replicated the local laboratory as closely as possible and created personalized photorealistic virtual replicas of the participants. This level of realism and personalization is not feasible in most cases. Work on virtually supported mind-body interventions presents very heterogeneous virtual environments and virtual bodies that are adapted to the goal of the task rather than to the user or do not include virtual bodies at all [14]. To generalize our results, it is necessary to replicate them in diverse virtual spaces, with less personalized or generic virtual bodies, or even without an anthropomorphic self-representation. We can only conclude that even in a scenario like ours, a negative influence of the embodiment of virtual bodies on body awareness cannot be excluded completely. In addition to the degree of realism, our choice of tasks also limits our results. The subjects in our study performed tasks designed to increase body awareness specifically. Since we focused on the application context of mind-body therapies, we initially limited our task selection. However, it remains to be investigated whether a more substantial effect on body awareness has to be expected in other tasks that are less movement- or body-focused. For further application, it would be vital to conduct investigations on body awareness in different virtual scenarios. Finally, our design is limited because a mirror exposure was performed at the end of each condition to highlight the difference between virtuality and reality more clearly. However, it limits the results on the influence of perspective to the extent that the post-experience surveys could not be investigated concerning perspective.

6 CONCLUSION

Virtual reality (VR) allows for replacing the visual information about our body with an arbitrary virtual self-representation (virtual body). In our study, we showed how embodying a photorealistically personalized virtual body affects the awareness of one's internal body signals (body awareness) and how the sense of embodiment is involved in the effects of virtuality and perspective on body awareness. Our results reveal that individuals perceive a lower sense of embodiment towards their virtual body in a virtual scenario than towards their real body in reality. They further indicate that individuals are slightly less aware of their internal body signals during the embodiment of a virtual body than in reality. A method often used to increase the sense of embodiment, a virtual mirror, did not positively affect the sense of embodiment in our study but caused individuals to focus more on their appearance than on their internal body signals. Finally, we could show that the sense of embodiment, and especially the feeling of being physically changed during an experience, mediates the effects of VR on body awareness. Future work should investigate whether the effects we found also appear with less personalized or generic virtual bodies in diverse virtual experiences. It should further investigate whether they also occur in different tasks that are not dedicated to body movement or body awareness.

ACKNOWLEDGMENTS

This research has been funded by the German Federal Ministry of Education and Research in the project ViTraS (16SV8219 and 16SV8225) and by the Bavarian State Ministry for Digital Affairs in the project XR Hub (A5-3822-2-16). We thank Roland Zechner for his support with our illustrations. Erik Wolf gratefully acknowledges a Meta Research PhD Fellowship.

REFERENCES

[1] Jascha Achenbach, Thomas Waltemate, Marc Erich Latoschik, and Mario Botsch. 2017. Fast Generation of Realistic Virtual Humans. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology* (Gothenburg, Sweden) *(VRST '17)*. Association for Computing Machinery, New York, NY, USA, Article 12, 10 pages. https://doi.org/10.1145/3139131.3139154
[2] Agisoft. 2021. Metashape Pro. http://www.agisoft.com. http://www.agisoft.com [Accessed August 26, 2022].
[3] Vivien Ainley and Manos Tsakiris. 2013. Body conscious? Interoceptive awareness, measured by heartbeat perception, is negatively correlated with self-objectification. *PloS one* 8, 2 (2013), e55568. https://doi.org/10.1371/journal.pone.0055568
[4] Pasquale Arpaia, Giovanni D'Errico, Lucio Tommaso De Paolis, Nicola Moccaldi, and Fabiana Nuccetelli. 2021. A Narrative Review of Mindfulness-Based Interventions Using Virtual Reality. *Mindfulness* 13, 3 (2021), 1–16. https://doi.org/10.1007/s12671-021-01783-6
[5] Autodesk. 2014. Character Generator. https://charactergenerator.autodesk.com. https://charactergenerator.autodesk.com [Accessed August 24, 2022].
[6] Andrea Bartl, Christian Merz, Daniel Roth, and Marc Erich Latoschik. 2022. The Effects of Avatar and Environment Design on Embodiment, Presence, Activation, and Task Load in a Virtual Reality Exercise Application. In *IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. https://downloads.hci.informatik.uni-wuerzburg.de/2022-ismar-ilast-avatar-environment-design-vr-exercise-application.pdf
[7] Andrea Bartl, Stephan Wenninger, Erik Wolf, Mario Botsch, and Marc Erich Latoschik. 2021. Affordable But Not Cheap: A Case Study of the Effects of Two 3D-Reconstruction Methods of Virtual Humans. *Frontiers in Virtual Reality* 2 (2021), 18. https://doi.org/10.3389/frvir.2021.694617
[8] Matthew Botvinick and Jonathan Cohen. 1998. Rubber hands 'feel' touch that eyes see. *Nature* 391, 6669 (1998), 756–756. https://doi.org/10.1038/35784
[9] Anne E. Cox, Sarah Ullrich-French, and Brian F. French. 2016. Validity evidence for the state mindfulness scale for physical activity. *Measurement in Physical Education and Exercise Science* 20, 1 (2016), 38–49. https://doi.org/10.1080/1091367X.

2015.1089404

[10] Nicole David, Francesca Fiori, and Salvatore M. Aglioti. 2014. Susceptibility to the rubber hand illusion does not tell the whole body-awareness story. *Cognitive, Affective and Behavioral Neuroscience* 14 (2014), 297–306. Issue 1. https://doi.org/10.3758/s13415-013-0190-6

[11] Henrique Galvan Debarba, Sidney Bovet, Roy Salomon, Olaf Blanke, Bruno Herbelin, and Ronan Boulic. 2017. Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality. *PLOS ONE* 12, 12 (12 2017), 1–19. https://doi.org/10.1371/journal.pone.0190109

[12] Henrique G. Debarba, Eray Molla, Bruno Herbelin, and Ronan Boulic. 2015. Characterizing embodied interaction in First and Third Person Perspective viewpoints. In *2015 IEEE Symposium on 3D User Interfaces (3DUI)*. Institute of Electrical and Electronics Engineers Inc., 67–72. https://doi.org/10.1109/3DUI.2015.7131728

[13] Diane Dewez, Rebecca Fribourg, Ferran Argelaguet, Ludovic Hoyet, Daniel Mestre, Mel Slater, and Anatole Lecuyer. 2019. Influence of personality traits and body awareness on the sense of embodiment in virtual reality, In 2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR). *Proceedings - 2019 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2019*, 123–134. https://doi.org/10.1109/ISMAR.2019.00-12

[14] Nina Döllinger, Carolin Wienrich, and Marc Erich Latoschik. 2021. Challenges and Opportunities of Immersive Technologies for Mindfulness Meditation: A Systematic Review. *Frontiers in Virtual Reality* 2 (2021), 29. https://doi.org/10.3389/frvir.2021.644683

[15] Nina Döllinger, Erik Wolf, David Mal, Nico Erdmannsdörfer, Mario Botsch, Marc Erich Latoschik, and Carolin Wienrich. 2022. Virtual Reality for Mind and Body: Does the Sense of Embodiment Towards a Virtual Body Affect Physical Body Awareness?. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, US). Association for Computing Machinery, New York, NY, USA, 1–8.

[16] Nina Döllinger, Erik Wolf, David Mal, Stephan Wenninger, Mario Botsch, Marc Erich Latoschik, and Carolin Wienrich. 2022. Resize Me! Exploring the User Experience of Embodied Realistic Modulatable Avatars for Body Image Intervention in Virtual Reality. *Frontiers in Virtual Reality* 3 (2022). https://doi.org/10.3389/frvir.2022.935449

[17] Empatica. 2020. E4 wristband for real-time physiological signals. https://www.empatica.com/research/e4/

[18] Eszter Ferentzi, Raechel Drew, Benedek T. Tihanyi, and Ferenc Köteles. 2018. Interoceptive accuracy and body awareness – Temporal and longitudinal associations in a non-clinical sample. *Physiology & behavior* 184 (2018), 100–107. https://doi.org/10.1016/j.physbeh.2017.11.015

[19] Maria L. Filippetti and Manos Tsakiris. 2017. Heartfelt embodiment: Changes in body-ownership and self-identification produce distinct changes in interoceptive accuracy. *Cognition* 159 (2017), 1–10. https://doi.org/10.1016/j.cognition.2016.11.002

[20] Sarah Friedrich, Edgar Brunner, and Markus Pauly. 2017. Permuting longitudinal data in spite of the dependencies. *Journal of Multivariate Analysis* 153 (2017), 255–265. https://doi.org/10.1016/j.jmva.2016.10.004

[21] Sarah Friedrich, Frank Konietschke, and Markus Pauly. 2019. Resampling-based analysis of multivariate data and repeated measures designs with the R package MANOVA. RM. *R J.* 11, 2 (2019), 380.

[22] Sarah Friedrich and Markus Pauly. 2018. MATS: Inference for potentially singular and heteroscedastic MANOVA. *Journal of Multivariate Analysis* 165 (2018), 166–179. https://doi.org/10.1016/j.jmva.2017.12.008

[23] Elisabeth Ganal, Andrea Bartl, Franziska Westermeier, Daniel Roth, and Marc Erich Latoschik. 2020. Developing a Study Design on the Effects of Different MotionTracking Approaches on the User Embodiment in Virtual Reality. *Mensch und Computer 2020-Workshopband* (2020).

[24] Gunvor Gard. 2005. Body awareness therapy for patients with fibromyalgia and chronic pain. *Disability and rehabilitation* 27, 12 (2005), 725–728. https://doi.org/10.1080/09638280400009071

[25] Jonathan Gibson. 2019. Mindfulness, Interoception, and the Body: A Contemporary Perspective. *Frontiers in Psychology* 10 (9 2019). https://doi.org/10.3389/fpsyg.2019.02012

[26] Geoffrey Gorisse, Olivier Christmann, and Simon Richir. 2017. First- and Third-Person Perspectives in Immersive Virtual Environments: Presence and Performance analysis of Embodied Users. *Frontiers in Robotics and AI* 4 (2017). https://doi.org/10.3389/frobt.2017.00033

[27] Amanda L. Gyllensten, Kent Skoglund, and Inger Wulf. 2018. *Basic Body Awareness Therapy: Embodied Identity*. Vulkan.

[28] Adam W. Hanley, Wolf E. Mehling, and Eric L. Garland. 2017. Holding the body in mind: Interoceptive awareness, dispositional mindfulness and psychological well-being. *Journal of Psychosomatic Research* 99 (8 2017), 13–20. https://doi.org/10.1016/j.jpsychores.2017.05.014

[29] Ding He, Fuhu Liu, Dave Pape, Greg Dawe, and Dan Sandin. 2000. Video-based measurement of system latency. In *International Immersive Projection Technology Workshop*. 1–6. https://doi.org/10.1080/09638280400009071

[30] Emily Hielscher and Regine Zopf. 2021. Interoceptive Abnormalities and Suicidality: A Systematic Review. *Behavior Therapy* 52, 5 (2021), 1035–1054. https://doi.org/10.1016/j.beth.2021.02.012 Interoceptive Dysfunction and Suicidality.

[31] Chin-Chang Ho and Karl F MacDorman. 2017. Measuring the uncanny valley effect. *International Journal of Social Robotics* 9, 1 (2017), 129–139. https://doi.org/10.1007/s12369-016-0380-9

[32] Yasuyuki Inoue and Michiteru Kitazaki. 2021. Virtual Mirror and Beyond: The Psychological Basis for Avatar Embodiment via a Mirror. *Journal of Robotics and Mechatronics* 33, 5 (2021), 1004–1012. https://doi.org/10.20965/jrm.2021.p1004

[33] Shunichi Kasahara, Keina Konno, Richi Owaki, Tsubasa Nishi, Akiko Takeshita, Takayuki Ito, Shoko Kasuga, and Junichi Ushiba. 2017. Malleable embodiment: Changing sense of embodiment by spatial-temporal deformation of virtual human body. *Conference on Human Factors in Computing Systems - Proceedings* 2017-May, 6438–6448. https://doi.org/10.1145/3025453.3025962

[34] Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology* 3, 3 (1993), 203–220. https://doi.org/10.1207/s15327108ijap0303_3

[35] Nayla M. Khoury, Jacqueline Lutz, and Zev Schuman-Olivier. 2018. Interoception in psychiatric disorders: A review of randomized controlled trials with interoception-based interventions. *Harvard review of psychiatry* 26, 5 (2018), 250. https://doi.org/10.1097/HRP.0000000000000170

[36] Konstantina Kilteni, Raphaela Groten, and Mel Slater. 2012. The sense of embodiment in virtual reality. *Presence: Teleoperators & Virtual Environments* 21, 4 (2012), 373–387. https://doi.org/10.1162/PRES_a_00124

[37] Konstantina Kilteni, Jean-Marie Normand, Maria V Sanchez-Vives, and Mel Slater. 2012. Extending body space in immersive virtual reality: a very long arm illusion. *PloS one* 7, 7 (2012), e40867.

[38] Marc Erich Latoschik, Jean-Luc Lugrin, and Daniel Roth. 2016. FakeMi: A Fake Mirror System for Avatar Embodiment Studies. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology* (Munich, Germany) *(VRST '16)*. Association for Computing Machinery, New York, NY, USA, 73–76. https://doi.org/10.1145/2993369.2993399

[39] Marc Erich Latoschik and Carolin Wienrich. 2022. Congruence and Plausibility, Not Presence: Pivotal Conditions for XR Experiences and Effects, a Novel Approach. *Frontiers in Virtual Reality* 3 (2022). https://doi.org/10.3389/frvir.2022.694433

[40] LimeSurvey GmbH. 2020. LimeSurvey 4. Retrieved September 30, 2021 from https://www.limesurvey.org https://www.limesurvey.org.

[41] Joan Llobera, Maria V. Sanchez-Vives, and Mel Slater. 2013. The relationship between virtual body ownership and temperature sensitivity. *Journal of the Royal Society Interface* 10 (8 2013). Issue 85. https://doi.org/10.1098/rsif.2013.0300

[42] Lara Maister and Manos Tsakiris. 2014. My face, my heart: Cultural differences in integrated bodily self-awareness. *Cognitive neuroscience* 5, 1 (2014), 10–16. https://doi.org/10.1080/17588928.2013.808613

[43] David Mal, Erik Wolf, Nina Döllinger, Mario Botsch, Carolin Wienrich, and Marc Erich Latoschik. 2022. Virtual Human Coherence and Plausibility – Towards a Validated Scale. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 788–789. https://doi.org/10.1109/VRW55335.2022.00245

[44] Wolf E. Mehling, Michael Acree, Anita Stewart, Jonathan Silas, and Alexander Jones. 2018. The multidimensional assessment of interoceptive awareness, version 2 (MAIA-2). *PloS one* 13, 12 (2018), 12 pages. https://doi.org/10.1371/journal.pone.0208034

[45] Wolf E. Mehling, Viranjini Gopisetty, Jennifer Daubenmier, Cynthia J. Price, Frederick M. Hecht, and Anita Stewart. 2009. Body awareness: construct and self-report measures. *PloS one* 4, 5 (2009), e5614. https://doi.org/10.1371/journal.pone.0005614

[46] Wolf E. Mehling, Judith Wrubel, Jennifer J. Daubenmier, Cynthia J. Price, Catherine E. Kerr, Theresa Silow, Viranjini Gopisetty, and Anita L. Stewart. 2011. Body Awareness: a phenomenological inquiry into the common ground of mind-body therapies. *Philosophy, ethics, and humanities in medicine* 6, 1 (2011), 1–12. https://doi.org/10.1186/1747-5341-6-6

[47] Bonnie Moradi and Julia R. Varnes. 2017. Structure of the objectified body consciousness scale: Reevaluated 20 years later. *Sex Roles* 77, 5 (2017), 325–337. https://doi.org/10.1007/s11199-016-0731-x

[48] Jean-Marie Normand, Elias Giannopoulos, Bernhard Spanlang, and Mel Slater. 2011. Multisensory stimulation can induce an illusion of larger belly size in immersive virtual reality. *PLOS ONE* 6, 1 (2011), e16128. https://doi.org/10.1371/journal.pone.0016128

[49] Martin P. Paulus and Murray B. Stein. 2010. Interoception in anxiety and depression. *Brain structure and Function* 214, 5 (2010), 451–463. https://doi.org/10.1007/s00429-010-0258-9

[50] Ivelina V. Piryankova, Hong Yu Wong, Sally A. Linkenauger, Catherine Stinson, Matthew R. Longo, Heinrich H. Bülthoff, and Betty J. Mohler. 2014. Owning an overweight or underweight body: Distinguishing the physical, experienced and virtual body. *PLOS ONE* 9, 8 (2014), e103428. https://doi.org/10.1371/journal.pone.0103428

[51] Beatriz Rey, Alejandro Oliver, Jose M. Monzo, and Inmaculada Riquelme. 2022. Development and Testing of a Portable Virtual Reality-Based Mirror Visual Feedback System with Behavioral Measures Monitoring. *International Journal of Environmental Research and Public Health* 19, 4 (2022), 20 pages. https://doi.org/10.3390/ijerph19042276

[52] Daniel Roth and Marc Erich Latoschik. 2020. Construction of the Virtual Embodiment Questionnaire (VEQ). *IEEE Transactions on Visualization and Computer Graphics* 26, 12 (2020), 3546–3556. https://doi.org/10.1109/TVCG.2020.3023603

[53] Rainer Schandry. 1981. Heart beat perception and emotional experience. *Psychophysiology* 18, 4 (1981), 483–488. https://doi.org/10.1111/j.1469-8986.1981.tb02486.x

[54] Kimberly B. Schauder, Lisa E. Mash, Lauren K. Bryant, and Carissa J. Cascio. 2015. Interoceptive ability and body awareness in autism spectrum disorder. *Journal of Experimental Child Psychology* 131 (3 2015), 193–200. https://doi.org/10.1016/j.jecp.2014.11.002

[55] Meral Sertel, Tülay T. Şimşek, and Eylem T. Yümin. 2021. The Effect of Body Awareness Therapy on Pain, Fatigue and Health-related Quality of Life in Female Patients with Tension-type Headaches and Migraine. *West Indian Medical Journal* 69, 2 (2021), 121–128. https://doi.org/10.7727/wimj.2015.304

[56] Richard Skarbez, Joe Gabbard, Doug A. Bowman, Todd Ogle, and Thomas Tucker. 2021. Virtual replicas of real places: Experimental investigations. *IEEE Transactions on Visualization and Computer Graphics* (2021), 1–1. https://doi.org/10.1109/TVCG.2021.3096494

[57] Bernhard Spanlang, Jean-Marie Normand, David Borland, Konstantina Kilteni, Elias Giannopoulos, Ausiàs Pomés, Mar González-Franco, Daniel Perez-Marcos, Jorge Arroyo-Palacios, Xavi Navarro Muncunill, et al. 2014. How to build an embodiment lab: achieving body representation illusions in virtual reality. *Frontiers in Robotics and AI* 1 (2014), 9. https://doi.org/10.3389/frobt.2014.00009

[58] Jan-Philipp Stauffert, Kristof Korwisi, Florian Niebling, and Marc Erich Latoschik. 2021. Ka-Boom!!! Visually Exploring Latency Measurements for XR. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 20, 9 pages. https://doi.org/10.1145/3411763.3450379

[59] Jan-Philipp Stauffert, Florian Niebling, and Marc Erich Latoschik. 2018. Effects of Latency Jitter on Simulator Sickness in a Search Task. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 121–127. https://doi.org/10.1109/VR.2018.8446195

[60] Jan-Philipp Stauffert, Florian Niebling, and Marc Erich Latoschik. 2020. Latency and Cybersickness: Impact, Causes, and Measures. A Review. *Frontiers in Virtual Reality* 1 (2020). https://doi.org/10.3389/frvir.2020.582204

[61] Ana Tajadura-Jiménez and Manos Tsakiris. 2014. Balancing the "inner" and the "outer" self: Interoceptive sensitivity modulates self-other boundaries. *Journal of Experimental Psychology: General* 143 (2014), 736–744. Issue 2. https://doi.org/10.1037/a0033171

[62] Galia Tanay and Amit Bernstein. 2013. State Mindfulness Scale (SMS): development and initial validation. *Psychological assessment* 25, 4 (2013), 1286. https://doi.org/10.1037/a0034044

[63] Manos Tsakiris, Ana Tajadura Jiménez, and Marcello Costantini. 2011. Just a heartbeat away from one's body: interoceptive sensitivity predicts malleability of body-representations. *Proceedings of the Royal Society B: Biological Sciences* 278, 1717 (2011), 2470–2476. https://doi.org/10.1098/rspb.2010.2547

[64] Manos Tsakiris, Gita Prabhu, and Patrick Haggard. 2006. Having a body versus moving your body: How agency structures body-ownership. *Consciousness and Cognition* 15, 2 (2006), 423–432. https://doi.org/10.1016/j.concog.2005.09.004

[65] Unity Technologies. 2020. Unity Real-Time Development Platform. Retrieved January 10, 2022 from https://unity.com

[66] Martin Usoh, Ernest Catena, Sima Arman, and Mel Slater. 2000. Using presence questionnaires in reality. *Presence* 9, 5 (2000), 497–503. https://doi.org/10.1162/105474600566989

[67] Valve Corporation. 2021. SteamVR. Retrieved January 10, 2022 from https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647

[68] Albert H. Van der Veer, Matthew R. Longo, Adrian J. Alsmith, Hong Yu Wong, and Betty J. Mohler. 2019. Self and body part localization in virtual reality: Comparing a headset and a large-screen immersive display. *Frontiers Robotics AI* 6 (2019). Issue APR. https://doi.org/10.3389/frobt.2019.00033

[69] Matti Vuorre and Niall Bolger. 2018. Within-subject mediation analysis for experimental data in cognitive psychology and neuroscience. *Behavior Research Methods* 50, 5 (2018), 2125–2143. https://doi.org/10.3758/s13428-017-0980-9

[70] Thomas Waltemate, Dominik Gall, Daniel Roth, Mario Botsch, and Marc Erich Latoschik. 2018. The impact of avatar personalization and immersion on virtual body ownership, presence, and emotional response. *IEEE Transactions on Visualization and Computer Graphics* 24, 4 (2018), 1643–1652. https://doi.org/10.1109/TVCG.2018.2794629

[71] Maren Wehrle. 2020. Being a body and having a body. The twofold temporality of embodied intentionality. *Phenomenology and the Cognitive Sciences* 19, 3 (2020), 499–521. https://doi.org/10.1007/s11097-019-09610-z

[72] Margaret Wilson. 2002. Six views of embodied cognition. *Psychonomic bulletin & review* 9, 4 (2002), 625–636. https://doi.org/10.3758/BF03196322

[73] Erik Wolf, Nina Döllinger, David Mal, Stephan Wenninger, Bartl Andrea, Mario Botsch, Marc Erich Latoschik, and Carolin Wienrich. 2022. Does Distance Matter? Embodiment and Perception of Personalized Avatars in Relation to the Self-Observation Distance in Virtual Reality. *Frontiers in Virtual Reality* 3 (2022). https://doi.org/10.3389/frvir.2022.1031093

[74] Erik Wolf, Nina Döllinger, David Mal, Carolin Wienrich, Mario Botsch, and Marc Erich Latoschik. 2020. Body Weight Perception of Females using Photorealistic Avatars in Virtual and Augmented Reality. In *2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. 462–473. https://doi.org/10.1109/ISMAR50242.2020.00071

[75] Erik Wolf, Marie Luisa Fiedler, Nina Döllinger, Carolin Wienrich, and Marc Erich Latoschik. 2022. Exploring Presence, Avatar Embodiment, and Body Perception with a Holographic Augmented Reality Mirror. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 350–359. https://doi.org/10.1109/VR51125.2022.00054

[76] Erik Wolf, Nathalie Merdan, Nina Döllinger, David Mal, Carolin Wienrich, Mario Botsch, and Marc Erich Latoschik. 2021. The Embodiment of Photorealistic Avatars Influences Female Body Weight Perception in Virtual Reality. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. IEEE, 65–74. https://doi.org/10.1109/VR50410.2021.00027