Virtual Reality for Mind and Body: Does the Sense of Embodiment Towards a Virtual Body Affect Physical Body Awareness?

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ABSTRACT

Mind-body therapies aim to improve health by combining physical and mental exercises. Recent developments tend to incorporate virtual reality (VR) into their design and execution, but there is a lack of research concerning the inclusion of virtual bodies and their effect on body awareness in these designs. In this study, 24 participants performed in-VR body awareness movement tasks in front of a virtual mirror while embodying a photorealistic, personalized avatar. Subsequently, they performed a heartbeat counting task and rated their perceived body awareness and sense of embodiment towards the avatar. We found a significant relationship between sense of embodiment and self-reported body awareness but not between sense of embodiment and heartbeat counting. Future work can build on these findings and further explore the relationship between avatar embodiment and body awareness.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Empirical studies in HCI*; *HCI theory, concepts and models*.

KEYWORDS

Virtual reality, embodiment, body awareness, mind-body-therapy

ACM Reference Format:
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 *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '22 Extended Abstracts), April 29-May 5, 2022, New Orleans, LA, USA*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3491101.3519613

CHI '22 Extended Abstracts, April 29-May 5, 2022, New Orleans, LA, USA

1 INTRODUCTION

Mind-body therapies represent a cluster of therapeutic approaches aiming to improve a person's general state of wellbeing and manage diseases by combining physical and mental exercises. Their idea is to engage patients in mindful self-observation and movement exercises to promote the integration of mind and body, resulting in increased awareness of bodily states and needs. Research on the efficacy of mind-body therapies demonstrates the potential of body awareness in managing a variety of disorders, including chronic pain [4], depression [9], as well as body weight and eating disorders [8, 39].

Based on the assumptions that immersion can positively affect the outcomes of mind-body therapy, recent developments tend to incorporate virtual reality (VR) into the design and execution of mind-body therapies. Various new interventions have been presented over the last decade. The link between body-based interactions in VR and body awareness has recently been discussed by various reviews on VR-based mindfulness [3, 10]. They point out the remaining lack of detail in the scientific results, specifically concerning the link between body awareness and the embodiment of virtual bodies [10]. To address this research gap, our paper explores whether the perceptual shift from the physical body towards a virtual body, also known as the sense of embodiment (SOE) [22], is related to body awareness in a mind-body-oriented task. In a short quantitative study, we examined whether SOE is related to different aspects of body awareness, namely self-reported body awareness and performance in a heartbeat counting task. The contribution of our work is twofold: (a) We provide initial insights into the relationship between avatar perception, namely SOE and a perceived uncanniness of the virtual body, and several aspects of body awareness. (b) We initiate a conversation toward a systematic evaluation of the effects of virtual bodies on body awareness.

2 RELATED WORK

Although there is a wide variety in the execution of mind-body therapies, one central element focuses on the physical body and aims to increase the patient's body awareness. Mehling et al. [29, p. 4] define body awareness as "the perception of bodily states, processes, and actions that is presumed to originate from sensory proprioceptive and interoceptive afferents and that an individual has the capacity to be aware of". Thus, it describes a conscious awareness of body posture signals (proprioception) and internal bodily signals (interoception), including specific sensations like heart activity and complex syndromes like relaxation or pain. Measures for body awareness are divided into body monitoring tasks designed to measure interoceptive accuracy, e.g., heartbeat counting [2], and self-report measures focusing on various aspects of body awareness, e.g., noticing bodily changes or regulating the attention towards the body [28].

Recent developments tend to incorporate VR in general and virtual bodies in particular into mind-body therapies. To systematically investigate the resulting benefits, it is necessary to identify the possible drivers of VR-supported therapy. Wienrich et al. [44] propose a framework for VR-based behavior therapy that efficiently summarizes the possibilities of VR design for therapeutic interventions and provides an overview of potential moderating and mediating responses to VR that should be considered. In addition to the immersive features of VR, such as the virtual environment and their effects on therapeutic target outcomes, their framework highlights the mediating effects of VR-specific perceptions that correspond with these immersive features and psychological drivers associated with the target outcomes. Döllinger et al. [10] adapted this framework for VR-supported mind-body therapy and provided an overview of combinations between design guidelines for mindfulness tasks and basic elements of VR design. They propose that in VR-based mind-body therapies using embodiment of a virtual body, the respective immersive feature is the sensory and behavioral representation of the virtual body. The two potential mediators in this scenario are body awareness as well as SOE towards a virtual body with respect to its proximity to mindfulness [30].

Besides the internal body signals mentioned above, humans permanently process and integrate a mixture of internal and external sensations [29]. VR builds on this perceptual integration. The presented external visual content is designed to carefully match the user's movements and actions and thus to create congruence between the user's external and internal perceptions. This way, a coherent virtual experience is created, which evokes a perception of the plausibility of the VR experience and consequently a sense of presence [24]. When embodying a virtual body, the congruency of visual and physical body perception enables a perceptual shift from the physical to the virtual body, inducing SOE towards the virtual body. Kilteni et al. [22, p. 375] define the SOE as "the sense that emerges when [the body's] properties are processed as if they were the properties of one's own biological body". They define the basis of SOE as a combination of bottom-up and top-down processing. The bottom-up processing of visuotactile, visuoproprioceptive, or visuomotor congruency supported by the visuospatial perspective manipulates external body signals and causes a shift in proprioception, a central element of body awareness. The top-down processing of the virtual body can either lead to a behavioral shift towards associated attitudes and behaviors of a non-personalized virtual body (Proteus effect) [33]. On the other hand, top-down processing leads to increased SOE towards personalized [43] and realistic [23] virtual bodies. However, realism and in specific photorealism of virtual bodies can lead to an unwanted feeling of eerieness (uncanny valley effect) [36], leading to aversion towards the virtual body and to reduced SOE [26].

There exist some investigations on the relationship between body awareness as defined by Mehling et al. [29] and the SOE towards a virtual body to predict applicability in mind-body therapies. Tsakiris et al. [40] showed that an initially high interoceptive accuracy, measured via a heartbeat counting task, negatively affected the SOE towards a virtual arm and hand. In their study, participants who performed better in monitoring and counting their heartbeat reported a lower SOE and vice versa. Reversely, Filippetti and Tsakiris [13] showed that embodiment leads to increased interoceptive accuracy for people with initially low accuracy, again measured via performance in heartbeat counting. In a more recent paper, Heeter et al. [18] revealed a positive impact of self-reported body awareness on the feeling of presence in a virtual environment. However, their environment did not include a virtual body. Similarly, it has been shown that having a virtual body positively affects presence [20, 46], but without measuring body awareness. To our knowledge, there does not exist research on self-reported body awareness and SOE. Additionally, with regard potential effects of uncanniness on body awareness, there has been no research so far.

Both body awareness and SOE arise from the integration of bodily signals. Yet, it remains unclear whether the focus on the visual information when embodying a virtual body can be a helpful tool in mind-body therapies and whether it supports or interferes with establishing a healthy body awareness. A negative effect of SOE on body awareness would severely limit the potential of VR for use in mind-body therapies and preclude one key driver, the Proteus effect. Before investigating the use of virtual bodies that differ from the user, it is necessary to determine whether the SOE to a realistic, personalized virtual body already affects body awareness.

The current paper reveals first insights into the relationship between SOE and body awareness. For our investigation, 24 participants embodied a photorealistic, personalized virtual body while repeatedly performing simple in-VR body awareness tasks in front of a virtual mirror. Then, they performed a heartbeat counting task and self-reported ratings of their SOE, body awareness, and perceived uncanniness of the virtual body. To increase the variance between repeated measures, we varied the presentation of facial movements between repetitions without making an inter-individual assumption about an effect. We assumed that (H1) a trait in body awareness predicts the impact of our task on the current state of body awareness, and (H2) in a VR body movement task, SOE is related to the current state of body awareness. We additionally examined whether top-down processes, like the perceived uncanniness of the virtual body, affected body awareness and whether SOE was related to mindfulness.

3 SYSTEM DESCRIPTION

3.1 Hard- and Software

Our VR setup consisted of an HTC Vive Pro Eye HMD, two handheld Valve Index controllers (Knuckles), and three HTC Vive Trackers 3.0, attached to the hip and each foot. For our purposes, the hardware components were sufficiently fast and accurately tracked using three SteamVR Base Stations 2.0 [31]. The HMD provided participants a resolution of 1440×1600 px per eye with a total field of view of 110° running at a refresh rate of 90 Hz. The participants' finger poses were tracked by the built-in proximity sensors of the Knuckles, their eye movements were captured by the HMD's built-in eye-tracking running at 120 Hz with an accuracy between 0.5° and 1.1° and end-to-end latency of around 80 ms [37], and their voices were recorded via the HMD's built-in microphone. The participants' facial expressions were not tracked. The setup was driven by a high-end VR-capable PC running our application fluently. For heartbeat measures, we used the Empatica E4 smartwatch [11].

The system was implemented using Unity 2020.3.11f1 LTS [41]. All VR-specific hardware was integrated using SteamVR version 1.16.10 and the corresponding Unity plugin version 2.7.3 [42]. For calculating the avatar's general body pose, we used the Unity plugin FinalIK version 2.0 [34] in conjunction with the system architecture introduced by Wolf et al. [45]. Eye animations were integrated using the Vive SRanipal runtime and SDK version 1.3.2.0. For implementing lip-sync, we used the Virtual Human Project toolkit [16]. All questionnaires were completed via LimeSurvey 4 [25].

3.2 Virtual Environment

We realized the virtual environment of our study by adapting an office room, initially obtained from the Unity Asset Store [1], to create a neutral and peaceful surrounding allowing for relaxation and self-awareness. In VR, a virtual full-body mirror was located on a wall at a distance of 1 m from the participant's position. We implemented the virtual mirror using a custom-written planar reflection shader. A marker on the floor of the virtual environment indicated the correct position for the participants during the study.

3.3 Avatar Generation and Animation

We generated photo-realistic and personalized avatars of the participants using the avatar reconstruction pipeline originally introduced by Achenbach et al. [1]. The pipeline first generates a dense point cloud of the participant's body using 94 high-quality images taken simultaneously from different perspectives. It further converts the point cloud into a fully rigged and textured mesh object, including blend shapes for facial expressions that can immediately be imported as a humanoid avatar into Unity. To induce SOE, the avatar was animated from an egocentric perspective according to the participant's movements in real-time using Unity's avatar animation system. For this purpose, we transferred the generated body and finger pose as well as the eye and lip movements to the participant's avatar using a custom-written retargeting script. The script pre-processes the raw data received from the tracking systems and maps it to the data structures required for proper avatar animation.

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

Figure 1: The figure shows a participant's egocentric view while performing the "rotation" task within the virtual environment. The mirror reflects its embodied and personalized avatar.

4 METHODS

Before conducting our study, we obtained ethical approval from the ethics committee of the Human Computer Media institute of the University of Würzburg with no further obligations.

4.1 Participants

A total of $N = 24$ volunteers participated in our investigation (8 male, 16 female). The participants were either undergraduate students ($n = 15$), employees ($n = 5$), currently unemployed ($n = 2$), self-employed ($n = 2$), and were granted either credit points or 30 euros for their participation. The mean age of participants was $M = 29$ years ($SD = 12.17$). Most participants ($n = 19$) stated to have less than three hours of experience in VR and had no experience with photorealistic, personalized avatars ($n = 22$).

4.2 Measures

As dependent variables for the perception of the virtual body, we measured (1) *SOE* and (2) the *perceived uncanniness of the virtual body*. As dependent variables for body awareness, we measured (3) *self-reported body awareness* together with a measure for *mindfulness* and (4) employed a heartbeat counting task measuring *interoceptive accuracy*. Before answering (1) and (2), participants were briefed to answer the questionnaires concerning their virtual body. Before answering (3), participants were briefed to answer the questionnaire about their physical body. Regarding (4), we calculated the difference between the real heartbeat and the estimated heartbeat count for each heartbeat measure (HCT error), as well as the difference of HCT error between pre-VR and post-VR measures (HCT change). As control variables, we included a measure for *trait body awareness* and captured symptoms for *simulation sickness*. The operationalization of the variables can be found in Table 1.

Table 1: The table shows the measures that are included in the analysis of this paper and the abbreviations used in the following.

Variable	Measure	Dimensions
Sense of embodiment	**VEQ**: Virtual Embodiment Questionnaire [35]	Body ownership, agency, change
Perceived uncanniness	**UVI**: Uncanny Valley Index [19]	Humanness, attractiveness, eerieness, spine-tingling
Self-reported body awareness	**SMS**: State Mindfulness Scale [38]	Body
Mindfulness	**SMS**: State Mindfulness Scale [38]	Mind
Interoceptive accuracy	**HCT**: Heartbeat Counting Task [2, 14]	Error: real vs. estimated count, change: post-VR vs. pre-VR
Trait body awareness	**MAIA**: Multidimensional Assessment of Interoceptive Awareness, Version 2 [28]	Total score
Simulation sickness	**SSQ**: Simulator Sickness Questionnaire [21]	Total score

4.3 In-VR Tasks

To elicit a feeling of body awareness and SOE, the participants performed various body movement exercises in front of a virtual mirror (see Figure 1). All exercises were based on Gyllensten et al. [17]'s description of Basic Body Awareness Therapy (BBAT) exercises. We included slightly shortened versions of the exercises *standing*, *rotation*, *wave*, and *push*. They were performed in a standing position and designed to stimulate different muscle groups. Participants were instructed to stand still and focus on perceiving their posture (standing). Subsequently, they were asked to rotate their torso (rotation), to perform rocking movements with their legs while letting their arms swing (wave), and to push their hands forwards while standing in a step position (push). For a more detailed description of the exercises, we refer to the work of Gyllensten et al. [17]. After instructing a movement task, we added the instruction to repeat the movement for 30 seconds until the next exercise was presented. Additionally, participants were instructed to focus on the stimulation of their muscles during the tasks rather than on their performance and to express their feelings during the exercises.

4.4 Procedure

The study followed the procedure illustrated in Figure 2. It was divided into scan and execution, performed on two different appointments. To increase the visual similarity between the participants and their virtual body, we asked them to wear the same clothing to both appointments. In the scan appointment, participants first received information about the local COVID-19 regulations and the experimental procedure and signed consent for body scan and participation. Then, the experimenter assessed the participant's body measures and performed the body scan following the local

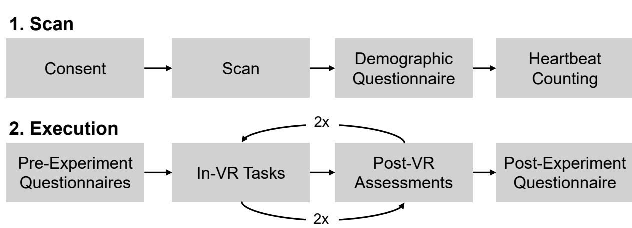

Figure 2: The chart shows the experimental procedure for both appointments.

workflow for body scanning and avatar generation. After the body scan, participants answered demographic questions and further questions about their prior VR experiences. Finally, they performed the heartbeat counting task for the first time. While performing the task, participants were sitting in a relaxed position and counted their heartbeat continuously. For 60 seconds, the heartbeat was measured without telling participants the time frame. The scan appointment lasted $M = 25$ minutes.

In the execution appointment, participants first answered the pre-experiment questionnaires, MAIA and SSQ, followed by two VR sessions. The two VR sessions varied in the visual representation of the virtual bodies' facial expressions (no facial expressions vs. eye and mouth movements), designed to increase variance in embodiment ratings. They were presented in counterbalanced order. Each VR session lasted 12 minutes. After a calibration of the avatar animation system, the participants were asked to describe their virtual body and express their feelings towards it, followed by the in-VR tasks. All in-VR asks were instructed via pre-recorded audio instructions. After the in-VR tasks, the participants answered SMS, VEQ, UVI, and performed heartbeat counting (post-VR assessments). Then, the VR exposure started for a second time. At the end of the session, participants answered the SSQ (post-experiment questionnaire). The execution appointment lasted $M = 68$ minutes.

5 RESULTS

All tests were performed using the statistics software R, version 4.1.0 [32]. The correlative results are shown in Table 2. In a pre-post comparison of the SSQ scores, we first tested whether participants had to be excluded due to simulator sickness. Results showed a maximum pre-post difference of 29.9 pts ($Md = 7.48, M = 15.27, SD = 18.25$) and a maximum post-measure of 74.8 pts for one participant. Therefore, none of the participants was excluded due to simulation sickness.

To test hypothesis H1, we analyzed the relation between trait body awareness (MAIA) and self-reported body awareness after the VR exposure (SMS body) and the relationship between interoceptive accuracy in the first heartbeat counting task (HCT error) and interoceptive accuracy increase after the VR exposure (HCT change). We calculated average scores for SMS body and HCT change over the two post-VR assessments. Subsequently, we calculated two simple linear regressions to predict SMS body based on the MAIA total score and HCT change based on the initial HCT error. In line with our hypothesis H1, MAIA ratings positively

Table 2: The table shows the results of the repeated measures correlations for self-reported body awareness (SMS body), interoceptive accuracy (HCT change) and mindfulness (SMS mind).

	SMS body				HCT change				SMS mind			
	r	*df*	*p*	95 % *CI* [*LL*, *UL*]	*r*	*df*	*p*	95 % *CI* [*LL*, *UL*]	*r*	*df*	*p*	95 % *CI* [*LL*, *UL*]
VEQ body ownership	.58	23	.002	[.22, .80]	.15	23	.475	[-.28, .53]	.42	23	.039	[.004, .71]
VEQ agency	.48	23	.014	[.09, .75]	-.13	23	.512	[-.52, .29]	.27	23	.196	[-.16, .61]
VEQ change	.26	23	.203	[-.17, .61]	.08	23	.715	[-.35, .47]	-.38	23	.064	[-.68, .04]
UVI humanness	.37	23	.070	[-.05, .68]	.05	23	.827	[-.37, .45]				
UVI attractiveness	.34	23	.092	[-.08, .66]	.12	23	.570	[-.31, .51]				
UVI eerieness	-.16	23	.446	[-.54, .27]	.32	23	.116	[-.10, .65]				
UVI spine tingling	.18	23	.387	[-.25, .55]	-.03	23	.899	[-.43, .39]				

predicted SMS body ratings in a significant regression equation, $F(1, 22) = 13.56, p = .001, R^2 = 0.35$. The mean scores in SMS body were equal to $1.81 + 0.64 \cdot$ (MAIA). SMS body increased 0.64 pts for each scale point in MAIA ratings. Additionally, HCT error in the first appointment negatively predicted HCT change in a significant regression equation, $F(1, 22) = 27.26, p < .001, R^2 = 0.53$. Thus, the HCT change was equal to $7.28 - 0.66 \cdot$ (initial HCT error). HCT change decreased 0.66 pts for each miscounted heartbeat in the initial HCT error.

To test hypothesis H2 on the relationship between SOE (VEQ) and body awareness (SMS body, HCT change), we analyzed the results of the two post-VR assessments on an intra-individual level. We calculated repeated measures correlations between SMS body and VEQ dimensions as well as HCT change and VEQ dimensions following the instruction of Bakdash and Marusich [5]. The correlative results are shown in Table 2. Partly in line with our hypothesis H2, the SMS body correlated positively with two of the three VEQ dimensions, body ownership, and agency, but not with VEQ change. The two significant regressions are depicted in Figure 3. Contrary to our assumptions, HCT change was not related to VEQ ratings.

Finally, we exploratory tested for a relationship between self-reported body awareness (SMS body) and perceived uncanniness of the virtual body (UVI), between interoceptive accuracy (HCT change) and perceived uncanniness of the virtual body (UVI), and between mindfulness (SMS mind) and SOE (VEQ). Here too, we used repeated-measures correlations. Neither the calculated correlations on SMS body and UVI nor the calculated correlations of HCT change and UVI revealed a significant relationship between self-reported body awareness or interoceptive accuracy and humanness, attractiveness, eerieness, or spine-tingling. The exploratory analysis of the SMS mind and VEQ revealed a significant positive correlation between SMS mind and VEQ body ownership. The intra-individual relationship between SMS mind and VEQ agency as well as SMS mind and VEQ change were not significant.

6 DISCUSSION

Our experiment aimed to gain first insights into the relationship between the SOE and different measures of body awareness in an in-VR body awareness task. We found a positive relationship between a trait in body awareness and self-reported body awareness after our task, indicating a good match between the two measures. Further, we could partly replicate the results of Filippetti and Tsakiris [13]. In line with their work, we found an impact of initial performance in the heartbeat counting task on performance improvement. Consequently, participants with initial good performance were less affected by the VR exposure. However, this result is easily explained by the fact that the performance of some participants was initially already very high, leaving only little room for improvement.

When comparing the SOE with self-reported body awareness on an intra-individual level, we found a positive relation between VEQ body ownership and VEQ agency with SMS body and between VEQ body ownership with SMS mind. When reporting an increased SOE in one VR session compared to another, participants rated both their body awareness and mindfulness higher. This relationship indicates potential for the use of embodiment and SOE in mind-body therapies and is in line with prior work on the positive impact of SOE on wellbeing [27]. Further, it raises the question, of whether the factors that affect SOE, such as visuomotor congruency, visuoproprioceptive congruency are equally important for the maintenance or increase of body awareness and mindfulness in a VR application. The results regarding the perceived uncanniness of the virtual body measured via the UVI did not reveal a significant relation with body awareness. However, we found a tendency towards a positive relationship between self-reported body awareness and the two dimensions of humanness and attractiveness. These results indicate that a rating of the own virtual body as more human or more attractive could be related to higher perceived body awareness. It delineates a possible influence of top-down processes on body awareness in virtual environments, similar to the effects of visual virtual body representations, e.g., personalization, on SOE [22, 43].

The results of the heartbeat counting task differ widely from the results of the self-reported body awareness, as we could find neither a relation between HCT change and SOE nor between HCT change and UVI. This outcome is in line with former investigations on the relationship of self-reported body awareness and interoceptive accuracy that showed the independence of self-report body awareness measures and body monitoring tasks [7, 12]. However, it contradicts the results of Tsakiris et al. [40], who found a negative impact of SOE on the performance in heartbeat counting, or the results of Filippetti and Tsakiris [13], who found a positive effect of SOE on interoceptive accuracy, at least for participants with low initial performance.

The findings of this study have to be interpreted with consideration of some limitations. First, we neither included a baseline

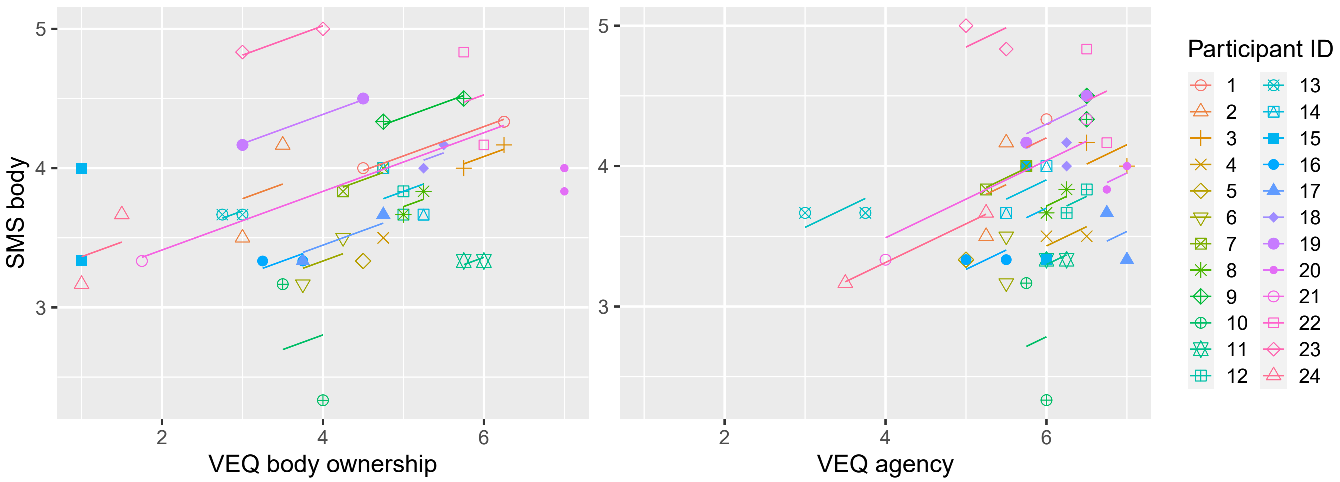

Figure 3: The chart shows the intra-individual relation between the two dimensions body ownership and agency (VEQ) and the self-report measure for body awareness (SMS body). Each dot represents one of the two post-VR assessments of a participant. Ratings of the same participant are given the same color, with corresponding lines to show the model fit for each participant. It depicts a consistent intra-individual dependency between sense of embodiment and body awareness over two VR exposures. A higher report in either agency or body ownership is associated with a higher rating in body awareness and vice versa.

condition without a virtual body nor outside VR. While our participants did not report discomfort during the exercises, future work should seek to validate them for usage in VR, as wearing the headset itself could have an impact on its outcomes concerning body awareness. Second, we did not manipulate the visuomotor or visuoproprioceptive congruency for a systematic variation in SOE. Gonzalez-Franco et al. [15] found that facial animations can systematically affect SOE towards virtual faces. However, they only found an effect on one single item, and the focus of our in-VR task was on full-body movements instead of focusing on facial expressions. Future investigations should investigate whether having a virtual body is per se beneficial in mind-body-oriented VR applications. Further, it should focus on varying embodiment conditions using more pronounced and task-relevant variations. Since personalized avatars become more affordable [6], it may also be worth exploring the role of avatar personalization in this context. Another limitation is that we assessed the heartbeat counting task on two different appointments, which may have increased variance in the data. However, we could still show that the HCT error in the initial assessment predicted the following HCT change after the VR exposure and thus replicated earlier results [13]. Finally, there are some limitations to our analysis. We examined several variables on SOE, the perceived uncanniness of the virtual body, and body awareness, leading to a large number of significance tests and thus possibly to a higher probability of false-positive results. However, given that this experiment is a first step in exploring the relationship between virtual body representation, SOE, and body awareness, we claim the importance of capturing small effects.

7 CONCLUSION

In this work, we investigated the relationship between body awareness and the sense of embodiment towards a virtual body. We found a positive correlation between SOE and self-reported body awareness and between SOE and mindfulness, indicating a potential for embodiment in virtual mind-body therapies. We further found a tendency for a positive relationship between perceived humanness and attractiveness of the virtual body on self-reported body awareness, indicating the importance of pleasant virtual bodies. This finding is specifically interesting for a potential use of non-personalized virtual bodies, e.g., when exploring a potential Proteus effect. Finally, we found that the performance in a heartbeat counting task was neither related to SOE nor any rating towards the virtual body, indicating that self-reported body awareness and body monitoring performance in VR require different manipulations. Future work can build on these results and investigate more deeply the potential of the embodiment of different types of virtual bodies as support for mind-body therapies.

ACKNOWLEDGMENTS

This research has been funded by the German Federal Ministry of Education and Research in the project ViTraS (16SV8219).

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