From Avatars to Agents: Self-Related Cues through Embodiment and Personalization Affect Body Perception in Virtual Reality

Marie Luisa Fielder*, Erik Wolf*, Nina Döllinger, David Mal, Mario Botsch, Marc Erich Latoschik and Carolin Wienrich

Fig. 1: A generated photorealistic virtual human of a female participant with generic (left) and personalized (right) texture. The virtual human's body weight is realistically modified between a BMI of 16 (left) and 36 (right) in two-point increments.

Abstract—Our work investigates the influence of self-related cues in the design of virtual humans on body perception in virtual reality. In a 2×2 mixed design, 64 participants faced photorealistic virtual humans either as a motion-synchronized embodied avatar or as an autonomous moving agent, appearing subsequently with a personalized and generic texture. Our results unveil that self-related cues through embodiment and personalization yield an individual and complemented increase in participants' sense of embodiment and self-identification towards the virtual human. Different body weight modification and estimation tasks further showed an impact of both factors on participants' body weight perception. Additional analyses revealed that the participant's body mass index predicted body weight estimations in all conditions and that participants' self-esteem and body shape concerns correlated with different body weight perception results. Hence, we have demonstrated the occurrence of double standards through induced self-related cues in virtual human perception, especially through embodiment.

Index Terms—Virtual human, virtual body ownership, agency, self-location, body image, body weight perception

1 Introduction

A negative or distorted perception of our physical body can profoundly affect our mental well-being, often manifesting in negative consequences such as body dissatisfaction [64], body shape concerns [38], or diminished self-esteem [49]. In severe cases, it can even contribute to the development of body-related disorders like obesity [69], body dysmorphic disorder [39], or eating disorders [8]. Despite knowing such conditions' consequences, their conventional treatment often faces high relapse rates [22,41] that necessitate the investigation of alternative treatment approaches. In recent years, the use of virtual humans in virtual reality (VR) has demonstrated great potential for addressing these challenges [35,44,71]. Exposing affected individuals to photorealistically personalized virtual humans, capable of being modified in body shape, can help uncover existing body misperceptions [36,43] or advance fundamental research on human body perception [46,67]. Moreover, the embodiment of such modulated virtual humans has shown the potential to stimulate an altered body perception by showcasing successful weight management results or developing a realistic impression of the current and desired body shape [17,56,82].

However, recent research has demonstrated that the visual perception of virtual humans, in their function as a predefined stimulus, can be significantly distorted by several individual-, system-, context- and application-related factors [12,13,66,68,79–81]. Understanding and considering such influences is critical when designing applications to support a positive body perception effectively. Concealed influences of unexplored factors, on the other hand, can potentially compromise such applications' desired outcomes. One less well-researched aspect so far is the role of self-related cues in the design of virtual humans, which we define as visual features directly tied to the user's identity and/or personal characteristics. Prior work indicates that such self-related cues might significantly impact the visual perception of the virtual human. For instance, Thaler et al. [66] observed that an individual's estimation of a virtual human's body weight was predicted by the individual's body weight only when the virtual human had a personalized texture, while Wolf et al. [81] discovered that an individual's body weight predicted the estimates of a virtual human's body weight only when the individual embodied the virtual human. Both observations may be related to the well-known use of so-called double standards. They describe the implicit use of different judgment criteria based on certain personal identification features (e.g., gender, age, or skin color) when evaluating different individuals who objectively have the same characteristics, leading to subjectively different judgments of the individuals. Doubled standards have previously been demonstrated in the judgment of real humans [23] and in evaluating comic-filtered humans on a screen [72]. Voges et al. [73] recently highlighted the presence of double standards

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in body perception when estimating body fat and muscle mass of one's own versus other bodies. However, it is unclear whether such double standards also exist in the judgment of virtual humans when presented with self-related cues through personalization or embodiment. Furthermore, the detailed impact of self-related cues in the design of virtual humans on their visual perception is a critical but under-researched topic that requires further investigation.

For this reason, we systematically investigated the role of self-related cues in the visual perception of virtual humans. We generated photorealistic virtual humans for each of our 64 participants using a state-of-the-art photogrammetry method. In a 2×2 mixed design, we modified self-related cues (1) by applying the generated self-related personalized or non-self-related generic texture to the virtual human. Additionally, we (2) utilized the virtual human as a self-related embodied avatar mimicking the participant's movements or a non-self-related autonomous agent moving independently. During the VR exposure, participants performed different body movement tasks before they estimated the virtual human's body weight to measure body perception. They observed the virtual human as an embodied avatar in a virtual mirror or as an autonomous agent in an adjacent room, facing each consecutively with a personalized and generic texture. After the VR exposure, we captured participants' sense of embodiment (SoE) and self-identification towards virtual humans as a manipulation check. We further assessed participants' body shape concerns and self-esteem as potential covariates and considered the influence of participants' body weight on their body weight estimations. After each condition, we conducted semi-structured interviews to better understand participants' experience with the presented virtual human.

Overall, our work contributes to the understanding of how double standards based on self-related cues can influence the appraisal of virtual humans. We further highlight the interplay between embodiment, personalization, individual BMI, and attitudinal components in shaping body weight perception of virtual humans. By uncovering these relations, our work aims to improve applications designed to enhance body image and mental well-being.

2 Related Work

The literature on body perception encompasses diverse factors influencing how individuals perceive their own and other bodies. In general, there is growing consensus that the image of our own body comprises a perceptual (bottom-up) and an attitudinal (top-down) component [8,32]. The perceptual component involves accurately perceiving body dimensions like size or weight. Known perceptual biases in this regard are the contraction bias, describing the use of a reference template for familiar stimuli around which body size perception is most accurate [9,55], and Weber's law, describing difficulties in perceiving body size changes with increasing size [10,28]. The attitudinal component considers an individual's attitudes and concerns toward their own body and shape. Cash and Deagle [8] suggest that variability in the attitudinal component mainly influences self-assessment, while perceptual biases tend to be consistent across individuals. This aligns with the concept of double standards in body perception, where individuals apply stricter criteria to evaluate their own bodies, particularly regarding factors like body fat and muscle mass, compared to evaluating others' bodies [72,73]. This discrepancy may stem from a body-related identity bias fostering a distorted body evaluation based on self-related identity cues.

2.1 Self-Related Cues on Virtual Humans

In prior research using virtual humans to work on body perception, two key factors influencing the perception of virtual humans through self-related cues have been identified. Firstly, individuals can embody a virtual human as their virtual body [78,81]. Secondly, virtual humans can be personalized in their texture and body shape to match the individual they represent visually [46,52,66,67]. Previous research showed that both factors evoke or intensify the sense of embodiment (SoE) and self-identification towards the virtual human [60,67,74,81]. SoE comprises the sense of owning, controlling, and being inside a virtual body, commonly known as virtual body ownership, agency, and self-location [42]. For our work, it is essential to distinguish between embodiment as experimental manipulation, which involves the physical integration and control of a virtual body, and SoE as a measure of the subjective feeling towards this virtual body [14,42]. Self-identification can be described as the "process of identifying a representation as being oneself" [29, p.1]. Following Wolf et al. [77], we differentiate self-identification into self-similarity, the perceived visual similarity between an individual and a virtual human, and self-attribution, the attribution of personal characteristics (external body features or internal character traits) to a virtual human. Both SoE and self-identification can be conveniently captured together by an extended version of the Virtual Embodiment Questionnaire (VEQ) [21,58].

When embodying a virtual human as an avatar, the visuomotor synchrony between an individual's movements and their avatar acts as a self-related cue, causing the perception of the avatar's body as their own body [62]. This process significantly increases SoE towards the embodied avatar compared to merely observing it without embodiment [58,81]. Research further demonstrated that the embodiment of a virtual human, especially the face (known as enfacement), increases self-identification with the virtual human [31,61,70]. Personalizing a virtual human's texture conveys additional self-related cues that can enhance an individual's SoE [30,60,74] and self-identification [60]. Overall, we expect that manipulating self-related cues, namely virtual human embodiment and personalization, reflects on the perceived SoE and self-identification towards a virtual human. We control for successful manipulation through these hypotheses derived from prior work:

H1.1: Participants rate the SoE towards embodied avatars higher than towards autonomous agents [58,81].

H1.2: Participants rate the SoE towards personalized virtual humans higher than towards generic ones [30,60,74].

H1.3: Participants rate the self-identification towards embodied avatars higher than towards autonomous agents [31,61,70].

H1.4: Participants rate the self-identification towards personalized virtual humans higher than towards generic ones [60].

2.2 Body Perception of Virtual Humans

Several works indicate the impact of self-related cues on individuals' perception of a virtual human's body. For instance, Piryankova et al. [52] and Thaler et al. [67] consistently demonstrated that participants were more accurate in estimating the body weight of non-embodied virtual humans with personalized textures compared to those with generic checkerboard textures. Thaler et al. [66] examined the influence of individuals' body weight on body weight estimation of non-embodied personalized and generic virtual humans, finding a significant impact only when participants estimated a personalized virtual human. The authors suspected that self-identification, based on perceived self-similarity, could explain these effects. They emphasized that personalized virtual humans closely resemble the participant's identity, resulting in more accurate body weight estimation. However, Mölbert et al. [46] observed contrasting results, with participants misestimating personalized virtual humans to a greater extent. Overall, personalizing a virtual human seems to affect body weight perception. However, the existing literature presents differing perspectives on the specific nature of this influence, motivating the present investigation on the role of personalization in the perception of virtual human bodies.

Concerning embodiment, Wolf et al. [78] observed a similar effect of individuals' body weight on body weight estimations for their generic embodied avatars as Thaler et al. [66] for their personalized non-embodied virtual humans. Consequently, the authors suspected that virtual human embodiment could influence body perception through self-related cues similar to personalization. In a follow-up study, Wolf et al. [81] confirmed this assumption by comparing body weight estimation between generic embodied avatars and generic autonomous agents, revealing an impact of individuals' body weight on estimates only for the embodied avatar but not for the agent. Furthermore, participants significantly underestimated the avatar's body weight compared to the agent. In a study by Neyret et al. [47], participants evaluated three generic virtual humans matching their perceived, desired, and actual body shapes, employed as either embodied avatars or autonomous agents. When observing their own body as an agent, the authors found that female participants perceived their real body shape more positively, without the negative preconceptions typically associated with their bodies. This led to a more positive evaluation of their own body shape. To systematically explore the impact of embodiment and personalization on estimations of virtual human body weight, we propose the following hypotheses based on relevant prior work:

H2.1: Participants estimate the body weight of embodied avatars less accurately than those of autonomous agents [81].

H2.2: Participants estimate the body weight of personalized virtual humans with a different accuracy than those of generic virtual humans [46, 52, 66, 67].

H2.3: Participants estimate the body weight of virtual humans with a different accuracy depending on the interaction between virtual humans' personalization and embodiment [46, 52, 66, 67, 81].

H2.4: Participants' body weight influences body weight estimations stronger when participants estimate embodied avatars or personalized virtual humans [66, 81].

2.3 Exploration of Further Potential Covariates

Previous research showed that self-esteem and body shape concerns influence how individuals perceive their real bodies [38, 49]. Concerning virtual humans, Park [50] emphasized self-esteem as a determining factor for body-related emotional responses when observing a personalized virtual human in VR. Building on the work of Cash and Deagle III [8], we conceptualize self-esteem and body shape concerns as attitudinal components that influence body perception only when the individual identifies with the body being appraised. Given that self-related cues like personalization and embodiment influence self-identification with virtual humans [31, 60, 61, 70], they could potentially moderate the effect of self-esteem and body shape concerns on body perception. Although Thaler et al. [67] found no significant impact of self-esteem and body shape concerns on individuals' estimations of virtual humans' body weight, we aim to re-explore these variables as covariates.

3 Method

3.1 Participants

Our study adhered to the principles of the Declaration of Helsinki and obtained approval from the local ethics review board at the University of Würzburg. We recruited 65 participants using the local participant management system. Thirty-one participants were undergraduate students and received course credit for participation; the other 34 participants received 15 € as compensation. All participants had (1) normal or corrected vision and hearing; (2) at least ten years of experience with the German language; (3) no diagnosed mental, psychosomatic, and body weight-related diseases; and (4) no known sensitivity to simulator sickness. We excluded one participant due to incorrect execution of experimental tasks. The remaining 64 participants (36 female, 28 male) were aged between 18 and 38 years ($M = 23.28$, $SD = 3.04$) and had the following ethnic distribution: 60 White, 1 Black, 1 MENA, 1 Asian, 1 Hispanic. Nine participants had no VR experience before the study, 45 used it between one and ten times, and ten used it more than ten times. All descriptive values and pairwise comparisons of demographic data and control measures between groups are shown in Tab. 2. If participants mentioned any discomfort regarding their body, we referred them to the support services from the Anorexia Nervosa and Associated Disorders (ANAD) organization.

3.2 Design

Our study employed a 2×2 mixed design with the independent variables virtual human embodiment as a between-subject factor and personalization as a within-subject factor. Participants were assigned either

Fig. 2: The top row shows the virtual environment during the embodiment conditions (E) and the bottom row during the non-embodiment conditions (NE). The left column shows personalized virtual humans (P), while the right column shows them non-personalized (NP).

to the embodiment condition (E), facing a virtual human as an embodied avatar, or the non-embodiment (NE) condition, facing it as an autonomous agent. In both conditions, participants subsequently encountered the virtual humans with personalized (P) and non-personalized (NP) texture (see Fig. 2). The condition assignment was always counterbalanced. As dependent values, we assessed the participants' perceived SoE, self-identification, and body weight perception of the virtual human. We further considered the personal body mass index (BMI), signs of simulator sickness, body shape concerns, and self-esteem as control variables. Finally, we conducted semi-structured interviews to capture participants' qualitative thoughts for each condition.

3.3 Apparatus

3.3.1 VR System

We utilized a Valve Index head-mounted display (HMD) with a 1440×1600 px per eye resolution and a total field of view of $114.1 \times 109.4°$ [77]. The refresh rate was set to 90 Hz. We used two Index controllers and three HTC Vive Trackers 3.0 to enable full-body tracking. One tracker was attached to the lower spine using a belt, and each foot had a tracker attached using Velcro straps (see Fig. 3). We developed our VR application using Unity 2020.3.18f1 LTS. It integrated the VR hardware using SteamVR version 1.20.4 and its corresponding SteamVR plugin version 2.7.3. The system was operated by a VR-capable workstation (Intel Core i7-7700K CPU, NVIDIA GeForce GTX 1080, 16 GB RAM) running Windows 10. We determined the motion-to-photon latency by counting frames [65] between real and rendered movements using an Aten VanCryst VS192 display port splitter that mirrored the HMD perspective on an ROG Swift PG43UQ monitor operating at 120 fps. Both movements were recorded simultaneously using an iPhone 12 at 240 fps. The analysis showed a latency of 14.4 ms for the HMD and 73.5 ms for the body tracking devices, which we considered sufficiently low [75].

3.3.2 Virtual Environment

We adapted our experimental environment from an office interior from the Unity Asset Store. It contained either a full-body mirror in the embodiment conditions (see Fig. 2, top) or a door frame to an adjacent

Fig. 3: A participant wearing VR equipment during embodiment calibration (left) and her personalized virtual human following her pose (right).

Fig. 4: Virtual humans showing the generic male (left) and female (right) textures used for the non-personalization (NP) conditions.

room in the non-embodiment conditions (see Fig. 2, bottom). We furnished the adjacent room differently to highlight that it was not a mirror image. Experimental instructions were displayed on a whiteboard left of the mirror/door frame. The virtual environment's orientation was aligned using the Kabsch algorithm [45], while its ground was adjusted by putting the controllers on the floor.

3.3.3 Virtual Human Generation

For each participant, we created a personalized virtual human using the method of Achenbach et al. [1]. The required hardware is set up in a laboratory of the University of Würzburg. It comprises 92 DSLR cameras mounted on a circular rig and a workstation (Intel Core i9-9900KF, NVIDIA RTX2080 Ti, 32 GB RAM) running Ubuntu 20. It captures multiple photos of a participant simultaneously to automatically generate a personalized 3D model and photorealistic texture that can be quickly imported into Unity using a custom FBX-based runtime importer. A detailed description of the process can be found in the work of Bartl et al. [3]. No further post-processing was performed on the virtual humans. We followed prior work for the generic virtual humans [52, 66] and replaced the generated 3D model's texture with a gender-matched generic texture (see Fig. 4).

3.3.4 Virtual Human Animation

In the embodiment conditions, we animated the virtual human as an embodied avatar from an egocentric perspective in real-time. The participants' body pose was approximated using inverse kinematics (IK) [2] provided by the Unity plugin FinalIK version 2.0. A custom algorithm requiring a short T-Pose (see Fig. 3, left) identified the tracker's positions on the body and calibrated the IK. The virtual human's fingers were animated using data from the proximity sensors of the controllers. A virtual mirror offered participants an allocentric view of the embodied avatar to promote self-identification [37] and facilitate body weight estimation [47, 68]. Following the guidelines of Wolf et al. [77], we placed the mirror at a distance of 2 m, resulting in a total self-observation distance of 4 m.

In the non-embodiment conditions, the autonomous agent was animated in the adjacent room using pre-recorded animations captured by the system described above. The view through the door frame provided an allocentric view similar to the embodiment condition. Since participants were not embodying the virtual human, they had no egocentric perspective on the virtual human but could see their controllers. The distance between the participant and the virtual human was 4 m.

3.3.5 Virtual Human Modification

We adapted a statistical model for weight gain/loss from prior work [18, 52] to modify the virtual humans' body weight (see Fig. 1). The model learns body weight variations for males and females using anthropometric data from the European subset of the CAESAR database [57]. It allows a dynamic and realistic change of virtual humans' body shape during runtime based on desired numerical body weight adjustments.

Participants had to modify the virtual human's body weight interactively for specific experimental tasks. To this end, we adapted the gesture-based interaction method from Döllinger et al. [18]. Participants could alter the virtual humans' body weight by pressing the trigger buttons on both controllers while moving them closer together to decrease or farther apart to increase weight. The speed and distance of the movement determined the degree of modification. We confined the adjustment to $\pm 35\,\%$ of the participant's actual body weight to ensure the body shape remained within a realistic and comfortable range.

3.4 Experimental Tasks

3.4.1 Body Movement Task

Participants performed five body movement tasks, each lasting 20 sec, while focusing on the presented virtual human. The tasks have been adapted from prior work [74, 78] and included waving with each arm, walking in place, circling arms, and circling hip. In the embodiment conditions, participants observed their body movements simultaneously on the mirror image of their embodied avatar to promote visuomotor coupling and induce SoE [63]. In the non-embodiment conditions, participants performed body movements in a different order than the autonomous agent to avoid visuomotor coupling.

3.4.2 Passive Estimation Task (PET)

The task was adapted from prior work [18, 80, 81] and used to capture participants' perception of the virtual human's body weight by estimating the body weight numerically. In nine trials, we modified the virtual human's original body weight counterbalanced in 5 % intervals within a range of $\pm 20\,\%$. After each modification, participants had to estimate the virtual human's body weight orally in kg. To avoid any hints, we blacked out the HMD during the modifications.

3.4.3 Active Modification Task (AMT)

The task was adapted from prior work [18, 47, 66] and used to examine participants' body weight perception by modifying the virtual human's body weight to match (1) their current and (2) their ideal/desired body weight. Before each estimation, the virtual human's body weight was set to a random value between $\pm 10\,\%$ of the participant's actual body weight while the HMD was blacked out.

3.5 Measures

3.5.1 Quantitative Questionnaires

We took multiple quantitative measures before, during, and after the VR experience. While literature considers short in-experience measures to capture VR-related qualia most valid, more comprehensive post-experience measures provide higher reliability and sensitivity [5, 19]. Participants answered pre- and post-experience questionnaires using LimeSurvey 4.5 and in-experience questions verbally. We used existing validated translated versions or back-and-forth translations to match the local language. Table 1 lists the questionnaires used.

Table 1: Overview of the questionnaires used during the study.

Questionnaire	Range	Measure
Sense of Embodiment		
pESQ [19]	[1 – 5]	Virtual Body Ownership (VBO)
	[1 – 5]	Agency (AG)
	[1 – 5]	Self-Location (SL)
VEQ [58]	[1 – 7]	Virtual Body Ownership (VBO)
	[1 – 7]	Agency (AG)
VEQ+ [21]	[1 – 7]	Self-Location (SL)
Self-Identification		
VEQ+ [21]	[1 – 7]	Self-Attribution (SA)
	[1 – 7]	Self-Similarity (SS)
Controls		
SSQ [4, 40]	[0 – 235.62]	Simulator Sickness
RSES [20, 59]	[0 – 30]	Self-Esteem
BSQ [53]	[34 – 204]	Body Shape Concern

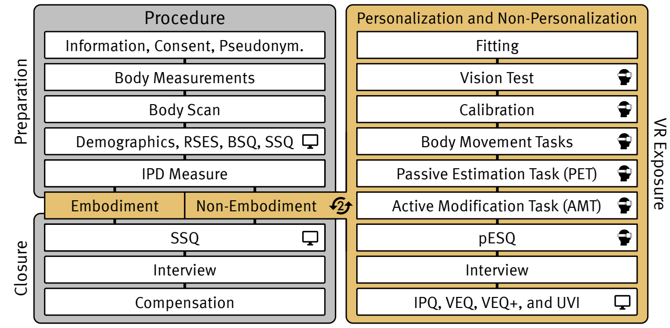

Fig. 5: Overview of the study (left) and VR exposure procedure (right).

3.5.2 Body Weight Perception

For PET, we calculated the percentage misestimation M for each performed body weight estimation using the formula $M = \frac{e-p}{p}$, where e was the estimated body weight and p was the presented body weight of the virtual human. A negative value indicates an underestimation and a positive value indicates an overestimation. We further calculated the average percentage misestimation as PET $\overline{M} = \frac{1}{n}\sum_{k=1}^{n} M_k$ and the absolute average percentage misestimation as PET $\overline{A} = \frac{1}{n}\sum_{k=1}^{n} |M_k|$. PET $\overline{M}$ describes the general ability to estimate the absolute body weight of the virtual human. PET $\overline{A}$ operationalizes the magnitude of individual estimations, indicating the absolute estimation accuracy between conditions. For AMT, we calculated the percentage misestimation M of a participant's current body weight using the formula $M = \frac{m-r}{r}$, where m was the virtual human's modified and r was the participant's current or ideal body weight. Compared to r, a negative value indicates an underestimation and a positive value indicates an overestimation.

3.5.3 Qualitative Interviews

We conducted semi-structured interviews with predefined questions post-experience to obtain more detailed information about the participant's opinions and to supplement the quantitative measures following an inductive analysis approach. The interviews contained questions on the perception of the virtual human, the experimental setting, and the interaction and self-identification with the virtual human. A list of all questions is in the supplementary material.

3.6 Procedure

Figure 5 visualizes our study's standardized procedure. The duration averaged 85 min, of which each VR exposure took around 10 min. Participants first consented to the study and generated two personal pseudonymization codes for storing the body scan and captured data. We instructed participants to wear tight-fitting, non-monochromatic clothing for the scan and remove glasses and other accessories. We measured body height and weight without shoes before the scan and captured the photos in the camera rig. While the avatar generation pipeline ran, participants answered the pre-questionnaire on a dedicated questionnaire computer. We further measured participants' interpupillary distance (IPD) using the smartphone app GlassesOn.

For the VR exposure, participants received information on how to wear the VR equipment and adjusted the HMD's lenses to the measured IPD. After the fitting, participants entered a black preparation environment where they performed all preparatory steps. The embodiment calibration was performed in all conditions to maintain comparability. Afterward, we started a pre-programmed experimental procedure, and the participants entered the virtual environment. The HMD was blacked out during all transitions. The experimental instructions were automatically played as pre-recorded voice instructions and shown on the virtual whiteboard. We instructed the participants to remain in the same spot marked by a sign on the ground in the virtual environment. The experimental tasks followed, as described in 3.4. As suggested by prior work [11, 68], participants were encouraged to turn in front of the virtual mirror during the PET and AMT to gain a holistic perspective of their embodied avatar. For the autonomous agent, turning was included in the pre-recorded animations. After finishing the tasks, participants answered in-experience questionnaires while the virtual human remained visible. After leaving VR, participants were interviewed and completed the post-experience questionnaires. The second VR exposure followed. Finally, participants completed the final post-questions and interviews.

4 Results

We conducted the statistical analysis utilizing R version 2022.07.2. We first compared the groups for homogeneity concerning relevant demographics and control measures using non-parametric Mann-Whitney-U or Wilcoxon tests as the data violated the assumption for normal distribution. We summarized the results in Tab. 2. We found no indications for a systematic simulator sickness when comparing SSQ pre-scores ($M = 13.15, SD = 13.92$) and post-scores ($M = 11.92, SD = 13.14$) ($z = -1.487, p = .137$). Four participants exceeded the simulator sickness threshold of 20 points [4], with the highest increase at 37.4 points. We excluded these participants, leaving 29 in the embodiment condition and 31 in the non-embodiment condition.

4.1 Manipulation Check

We performed 2×2 MANOVAs for all dimensions of SoE, combining in-exposure and post-exposure measures. Due to violating multivariate normality, we used the modified ANOVA statistic (MATS) for multivariate and data with repeated measures [24], calculated with the R package MANOVA.RM [25]. We applied a bootstrap approach with 1000 iterations to mitigate bias [26]. We conducted post hoc analyses using 2×2 mixed ANOVAs. For variables not meeting normality or homoscedasticity assumptions, we compared results with non-parametric analyses of longitudinal data [7] from the R package nparLD [48] and found no difference in the results. Therefore, we reported the results of the parametric tests for all variables. Descriptive data and results of the ANOVAs can be found in Tab. 3, with plots in Fig. 6. We performed all tests against an α of .05.

Table 2: Descriptive values of the control measures for the between factor embodiment (E/NE) and results of pairwise comparisons.

	E	NE	
	M (*SD*)	*M* (*SD*)	Test statistics
Age	23.10 (0.29)	23.42 (23.47)	$U(29,31) = 459.0, p = .887$
BMI	22.68 (0.43)	23.26 (0.36)	$U(29,31) = 368.0, p = .228$
BSQ	62.58 (3.02)	62.79 (2.83)	$U(29,31) = 442.0, p = .912$
RSES	22.00 (0.66)	23.42 (0.55)	$U(29,31) = 371.0, p = .244$
Pre-SSQ	14.96 (1.78)	11.34 (1.68)	$U(32,32) = 602.5, p = .219$
Post-SSQ	15.66 (1.91)	8.18 (1.16)	$U(32,32) = 667.5, p = .034$

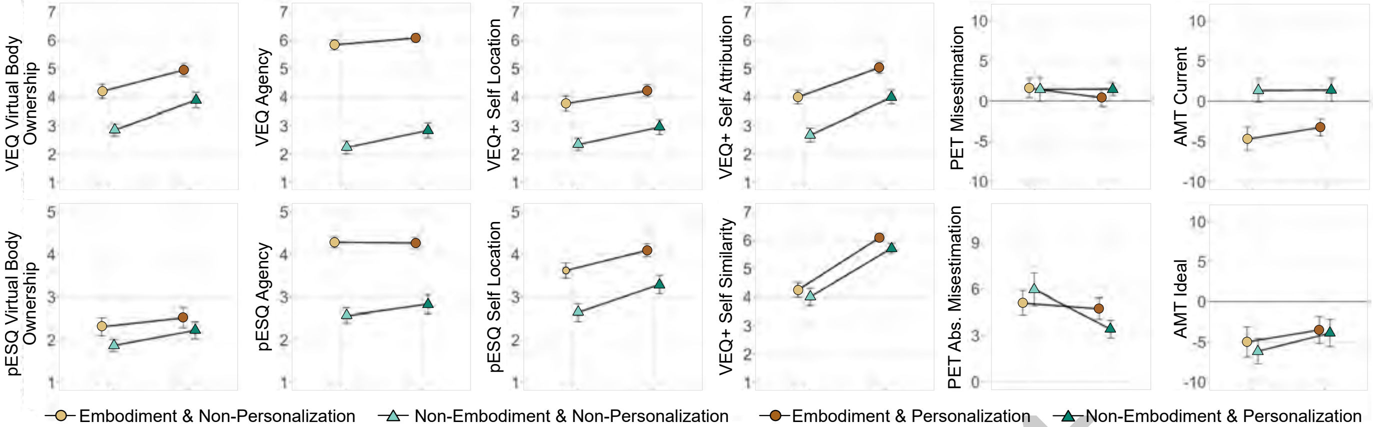

Fig. 6: Interaction plots for all descriptive mean values for SoE, self-identification, and the body weight perception tasks. The personalization factor is plotted on the x-axis, while the separate lines represent the embodiment factor. Error bars show the standard error.

4.1.1 Sense of Embodiment (SoE)

Our MANOVAs revealed main effects of embodiment for VBO ($MATS = 27.854, p < .001$), AG ($MATS = 355.425, p < .001$), and SL ($MATS = 53.96, p < .001$) and personalization for VBO ($MATS = 15.47, p < .001$), AG ($MATS = 4.657, p = .001$), and SL ($MATS = 13.699, p < .001$). We found no interactions. Post-hoc ANOVAs revealed significantly higher scores for embodied avatars in-exposure (pESQ) AG and SL, but not for VBO. Post-exposure measures (VEQ) showed higher scores for embodiment for VBO, AG, and SL. Hence, we confirmed H1.1. Personalized virtual humans were rated in-exposure (pESQ) higher than generic ones for VBO and SL, but not for AG. Post-exposure (VEQ) measures showed higher scores for personalized virtual humans as for non-personalized ones for VBO, AG and SL. Hence, we confirmed H2.1.

4.1.2 Self-Identification

Our ANOVA model revealed that embodied avatars were rated higher as autonomous agents for SA, but not for SS. Hence, we only partially confirmed hypothesis H1.3. Furthermore, we found significantly higher ratings for personalized virtual humans for SA and SS. Hence, we only partially confirmed hypothesis H1.4. Overall, we found no interaction effects.

4.2 Body Weight Perception

Following Sec. 4.1, we conducted separate 2×2 mixed ANOVAs for PET and AMT measures. Descriptive data and results of the ANOVAs can be found in Tab. 3, with plots in Fig. 6. Additionally, we calculated correlations between the participant's BMI and PET and AMT's body weight estimation variables. We further calculated correlations between the body weight modification levels of PET $\overline{M}$ and PET $\overline{A}$. Find all correlations in Tab. 4. We used Spearman's correlations since the variables were not normally distributed and had no linear relationship. To investigate the effect of BMI concerning our hypothesis H2.4, we calculated moderations for each detected correlation with BMI as the independent variable, the body weight estimation variable as the dependent variable, and the factors personalization and embodiment as moderator variables using model two of the R PROCESS macro [33, 34].

4.2.1 Passive Estimation Task (PET)

We found no significant main or interaction effects for embodiment and personalization in PET $\overline{M}$. However, we found a significant correlation between body weight modification level and PET $\overline{M}$ ($r(1078) = -0.392, p < .001$), as shown in Fig. 7, top. For PET $\overline{A}$, our ANOVA revealed significantly lower values for personalized virtual humans, but no effect of embodiment. The ANOVA showed a tendency for an interaction between both factors. We observed a sig-

Table 3: Descriptive values and mixed ANOVAs calculated with the main and interaction effects (ME and IE) for each experimental condition. E and NE label the embodiment factor, P and NP the personalization factor. The number of degrees are (1,58) for each ANOVA. Statistical significance indicators: $^* p < 0.05$; $^\dagger p < 0.01$; $^\ddagger p < 0.001$.

	E/P	E/NP	NE/P	NE/NP	ME-E			ME-P			IE		
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*F*	*p*	η^2	*F*	*p*	η^2	*F*	*p*	η^2
Sense of Embodiment													
pESQ VBO	2.52 (0.24)	2.31 (0.21)	2.22 (0.20)	1.87 (0.14)	2.14	.149	.036*	4.58	.037*	.073	–	–	–
VEQ VBO	4.95 (0.23)	4.12 (0.25)	3.89 (0.28)	2.85 (0.22)	15.59	$< .001^\ddagger$	.213	30.23	$< .001^\ddagger$	.213	–	–	–
pESQ AG	4.27 (0.13)	4.28 (0.13)	2.83 (0.22)	2.56 (0.18)	50.48	$< .001^\ddagger$	.465	1.50	.226	.025	–	–	–
VEQ AG	6.08 (0.14)	5.84 (0.18)	2.84 (0.27)	2.23 (0.23)	155.20	$< .001^\ddagger$	.728	12.66	$< .001^\ddagger$	.179	–	–	–
pESQ SL	4.09 (0.15)	3.62 (0.18)	3.29 (0.22)	2.64 (0.21)	13.65	$< .001^\ddagger$	.190	21.09	$< .001^\ddagger$	.267	–	–	–
VEQ+ SL	4.22 (0.21)	3.77 (0.27)	2.95 (0.26)	2.34 (0.21)	20.18	$< .001^\ddagger$	.258	11.20	.001†	.162	–	–	–
Self-Identification													
VEQ+ SA	5.03 (0.19)	3.99 (0.24)	3.99 (0.24)	2.67 (0.24)	20.32	$< .001^\ddagger$	.219	69.61	$< .001^\ddagger$	.548	0.31	.578	.017
VEQ+ SS	6.08 (0.13)	4.24 (0.26)	5.72 (0.17)	4.00 (0.31)	1.48	.229	.025	75.34	$< .001^\ddagger$	.565	0.10	.758	.002
Body Weight Perception in PET													
$\overline{M}$ in %	0.41 (1.13)	1.60 (1.20)	1.49 (0.80)	1.47 (1.50)	0.10	.757	.002	0.66	.420	.011	0.71	.403	.012
$\overline{A}$ in %	4.74 (0.70)	5.10 (0.78)	3.41 (0.57)	5.98 (1.06)	0.06	.815	.000	5.99	.017*	.094	3.38	.071	.055
Body Weight Perception in AMT													
Cur. in %	-3.32 (1.18)	-5.24 (1.55)	1.4 (1.44)	1.46 (1.49)	10.56	.002†	.154	0.87	.356	.015	0.93	.323	.017
Ideal in %	-3.38 (1.84)	-5.02 (2.05)	-3.66 (1.74)	-6.00 (1.62)	0.07	.788	.001	3.37	.072	.055	0.10	.750	.002

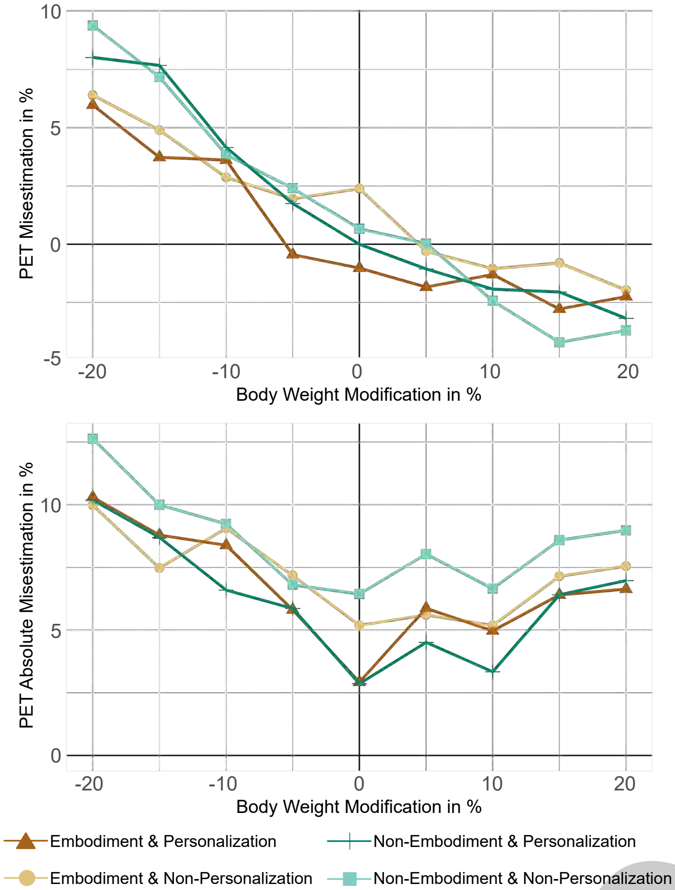

Fig. 7: Average body weight misestimation PET $\overline{M}$ (top) and absolute average body weight misestimation PET $\overline{A}$ (bottom) in relation to body weight modifications during the PET in % for each condition.

nificant correlation between the body weight modification level and PET $\overline{A}$ ($r(1078) = -0.133, p < .001$). PET $\overline{A}$ per body weight modification level for each condition is shown in Fig. 7, bottom. We partially confirmed H2.2 but did not confirm H2.1 and H2.3 for PET.

4.2.2 Active Modification Task (AMT)

For AMT current, we revealed a significant main effect for embodiment. Participants underestimated their own body weight for embodied avatars, while they overestimated it for autonomous agents. We found no effect of personalization or interaction. For AMT ideal, tendencies suggested that participants' ideal body weight was closer to their real body weight for personalized virtual humans. However, we observed no main effect for embodiment or interaction. Overall, we confirmed H2.1 but did not confirm H2.2 and H2.3.

4.2.3 Influence of BMI

We observed a significant correlation between participants' BMI and PET $\overline{M}$ ($r(118) = -0.353, p < .001$), but not with PET $\overline{A}$. Moderation analysis indicated no effect of BMI on PET $\overline{M}$ moderated by embodiment or personalization, thus not confirming H2.4 for PET. Similarly, although we revealed a correlation between participants' BMI and AMT current ($r(118) = 0.24, p = .008$), moderation analysis did not show any effects of BMI moderated by embodiment or personalization, thus not confirming H2.4 for AMT. We found a significant correlation between AMT ideal and participants' BMI ($r(118) = -0.282, p = .002$), but moderation analysis showed no interaction between BMI and either embodiment or personalization.

4.3 Exploration of Further Potential Covariates

We conducted Spearman correlations between self-esteem, body shape concern, and PET and AMT measures to explore additional potential covariates. The resulting correlations are presented in Tab. 4. To investigate potential double standards in body weight estimations, multiple linear regressions were performed for significant correlations to determine predictive effects regarding embodiment and personalization.

Table 4: Correlations between RSES, BSQ, BMI, and Body Weight Modification Level (BWML) and PET $\overline{M}$, PET $\overline{A}$, AMT current, and AMT ideal. Statistical significance indicators: $^{*}\,p < 0.05$; $^{\dagger}\,p < 0.01$; $^{\ddagger}\,p < 0.001$.

	PET $\overline{M}$	PET $\overline{A}$	AMT Current	AMT Ideal
RSES	$0.24^{\dagger}$	-0.01	-0.17	-0.08
BSQ	-0.09	-0.07	$0.28^{\ddagger}$	$-0.41^{\ddagger}$
BMI	$-0.35^{\ddagger}$	0.45	$0.24^{\dagger}$	$-0.28^{\dagger}$
BWML	$-0.39^{\ddagger}$	$-0.13^{\ddagger}$	-	-

4.3.1 Self-Esteem and Body Shape Concerns

For PET $\overline{M}$, we found a significant correlation with self-esteem ($r(118) = 0.236, p = .009$). However, the subsequent regression analysis showed no significant results ($F(3,116) = 1.284, p = .283$). Moreover, AMT current correlated with the BSQ score ($r(118) = 0.28, p = .002$). The subsequent multiple linear regression revealed that AMT current was significantly predicted by participant's body shape concerns ($t(116) = 3.963, p < .001$) and embodiment ($t(116) = 4.248, p < .001$), but not by personalization ($t(116) = 0.663, p = .509$). The significant regression equation ($F(3,116) = 11.3, p < .001$) follows the equation AMT current $= -12.069 + 0.12 \cdot$ Body Shape Concerns $- 5.69 \cdot$ Embodiment $+ 0.89 \cdot$ Personalization, with "1" denoting the embodied/personalized condition and "0" indicating the non-embodied/non-personalized condition. We also found significant correlations between AMT ideal and BSQ ($r(118) = -0.414, p < .001$).

4.4 Qualitative Feedback

We evaluated the interviews by clustering all answers within the context of their question on sticky notes following a thematic analysis [6]. The following sections present the feedback concerning the impact of personalization and embodiment on PET and AMT for our conditions, which were completed by 32 participants each.

4.4.1 The Impact of Embodiment and Personalization in PET

Fourteen out of 32 participants found it easy to estimate the personalized embodied avatar's body weight due to the familiar personalized appearance, using their own body as reference points and recognizing familiar clothing. Synchronous movements of the avatar allowed observing the body weight in the mirror from all sides, with the lateral view of the belly crucial for estimation. Three participants described the body weight estimation as easy due to strong identification with the avatar. Only two participants described the body weight estimation of the generic embodied avatar as easy because of its unfamiliar appearance, leading to fewer preconceptions and a more objective estimate. On the other hand, 21 participants found it difficult due to unfamiliar clothing, body types, unknown muscle-fat ratios, and unknown original weight. For most participants, rotating in front of the mirror helped obtain different angles for viewing body weight and body parts.

Fifteen participants out of 32 found it easy to estimate the body weight of the personalized autonomous agent. They attributed this ease to the personalized appearance, personal body reference points, or knowledge about their own body with different body weights. Two participants noted a more intense experience than estimating the generic agent due to a stronger identification with the personalized agent. Conversely, 14 participants found the estimation difficult, mainly because they struggled to determine weight based solely on body shape. Four participants felt the agent's foreign movements made them estimate a stranger's body weight. Five participants found it easy to estimate the body weight of the generic agent, approaching it as estimating a stranger, leading to a more objective estimate. However, 23 participants found estimation difficult due to unfamiliar appearance, lack of reference points, and clothing hindrances.

4.4.2 The Impact of Embodiment and Personalization in AMT

Nineteen out of 32 participants described the AMT of the personalized embodied avatar as easy. The personalized appearance facilitated higher identification with the avatar, making it easier to project one's own body weight and use known reference points. However, eleven participants found the estimation difficult, expressing concerns about perceiving the avatar as distorted due to high identification, leading to underestimating their current body weight. Eleven participants felt that the generic avatar's body weight was easy to estimate because they saw it as a stranger, allowing for objective assessment. In comparison, 20 participants found it difficult due to its foreign appearance and lack of knowledge about its original body weight.

Eighteen out of 32 participants found it easy to estimate the personalized autonomous agent's body weight due to the personalized appearance, allowing them to use personal reference points. However, seven participants found the agent's personalization hindering. High identification led to their own mental body image influencing the estimation, resulting in a bias towards their ideal body weight. The agent's foreign movements helped three participants view the agent's body more objectively, perceiving it as its own person. Eighteen participants found it difficult to estimate the generic agent. They struggled to project their body weight to a stranger, found the agent's clothing hindering, and lacked reference points due to different appearances.

5 Discussion

We aimed to investigate the impact of self-related cues in the design of virtual humans for applications supporting body perception. In detail, we examined how the manipulation of embodiment and personalization shapes body perception. Our manipulation check (H1.1 – H1.4) confirmed that participants felt a higher SoE and self-identification when facing embodied and/or personalized virtual humans. Depending on the body weight estimation task, either embodiment or personalization significantly impacted body weight perception, with no interaction between the factors (H2.1 – H2.3). Embodiment or personalization of virtual humans did not moderate the influence of participants' BMI (H2.4). Finally, our exploratory analysis revealed correlations between self-esteem, body shape concerns, and body weight estimations.

5.1 Embodiment and Personalization Increase SoE and Self-Identification Towards a Virtual Human

Consistent with H1.1 and the results of previous work [58, 81], we observed a significantly higher SoE for embodied avatars compared to autonomous agents. Only pESQ VBO showed no significant differences, likely attributable to the wording of the single item "I felt like the environment affected my body" [19]. It diverges from the common understanding of VBO as accepting the virtual body as the real body [42]. Instead, it aligns more with the concept of "change" as proposed by Roth and Latoschik [58]. Future pESQ revisions should consider this distinction. We further confirmed H1.2 and showed a significantly higher SoE for personalized virtual humans than generic ones. Our results differ from previous work, which only found effects on VBO but not on agency and self-location [30, 74]. Interestingly, personalization also affected SoE towards autonomous agents across all dimensions, expanding previous research that only examined embodied avatars [16, 30, 60, 74]. The effect on autonomous agents could be due to the operationalization of SoE, as items often refer to an arbitrary virtual body [19, 51, 58]. However, it is also possible that personalization generates SoE towards autonomous agents. Future work needs to investigate the actual reason.

Partially confirming H1.3, we found significantly higher self-attribution towards embodied avatars than autonomous agents but no differences in self-similarity. Our findings extend enfacement research [31, 61, 70], revealing that virtual human embodiment induces self-identification, particularly through self-attribution. We further confirmed H1.4 and the results of previous work [60, 66], as participants reported a greater self-attribution and self-similarity when facing a personalized virtual human compared to a generic one.

In summary, we found that self-related cues through embodiment and personalization in the design of virtual humans significantly increase SoE and self-identification. Our results imply potential for future work that desires either to promote or avoid users associating themselves with a virtual human. The results further confirm a successful experimental manipulation of self-related cues indispensable for our further analysis of their effects on body perception.

5.2 The Influence of Self-Related Cues on Body Weight Perception is Task-Depended

H2.1 assumed that body weight estimations of embodied avatars would be less accurate than those of autonomous agents. While the results for PET $\overline{M}$ and PET $\overline{A}$ did not support H2.1, we could confirm it for AMT current. Participants significantly underestimated their current body weight on embodied avatars, while estimating agents led to a slight overestimation. These results align with Wolf et al. [81], where participants consistently underestimated generic embodied avatars' body weight in a simple numeric body weight estimation task (without employing body weight modifications). At the same time, they accurately estimated it for generic agents. The results are also consistent with Neyret et al. [47], who noted a potentially more objective self-view when participants observed themselves from an allocentric perspective, and our observed qualitative statements, where participants reported the estimation of agents as easier due to a more objective perspective. Overall, the effects on AMT current extend previous research [23, 72, 73] by indicating that double standards (1) also occur in the evaluation of virtual humans and (2) can be elicited by embodiment.

H2.2 further hypothesized that body weight estimations would differ in accuracy between personalized and generic virtual humans. While we found no differences for PET $\overline{M}$ and AMT current, personalized virtual humans were estimated significantly more accurately in PET $\overline{A}$ than generic ones. This aligns with prior work [52, 68] but contradicts Mölbert et al. [46], who found less accurate estimations of personalized virtual humans. Our results are also consistent with participants' qualitative feedback, revealing that body weight estimations were easier with familiar reference points (e.g., cloth or face) of personalized virtual humans. Contrary to Voges et al. [72, 73], we observed no signs of double standards leading to a more biased evaluation of personalized virtual humans. When analyzing the impact of personalization on AMT ideal, we observed notable descriptive differences, with participants rating their ideal body weight closer to their original weight when assessing a personalized virtual human. The personalization of the virtual human might have served as a strong self-related visual anchor, nudging the desired ideal body weight towards the actual body weight and leading to a higher tolerance of being satisfied with a certain body weight.

Contradicting H2.3, we found no interaction effect between personalization and embodiment for body weight perception. However, trends in PET $\overline{A}$ suggested an improved weight estimation for personalized agents compared to other conditions. The variation in the influence of virtual human embodiment and personalization on body weight perception across specific tasks may also explain the absence of interactions.

In summary, we showed that the impact of virtual human embodiment and personalization on body weight perception can depend on a specific task and its quantification. It implies that the choice of a task in studies investigating body perception using virtual humans can lead to different results, emphasizing the importance of carefully selecting tasks operationalizing specific aspects of body perception. As prior work [54, 82], we advise caution when comparing and interpreting results across studies utilizing different methodologies and tasks.

5.3 BMI Influences Body Weight Perception Independently of Self-Related Cues

H2.4 suggested that the participants' individual BMI has a stronger influence on body weight estimations for virtual humans featuring self-related cues. However, our study showed no significant moderation of virtual human embodiment and personalization on the influence of BMI on body weight perception. Therefore, we could not replicate the findings of Thaler et al. [66] for personalization and Wolf et al. [81] for embodiment. In contrast, we observed significant correlations between the individuals' BMI and all body weight estimations except PET $\overline{A}$, indicating that the individual's BMI influences body weight estimations of virtual humans across all conditions. This consistent influence could result from matching the participants' gender, height, and body shape with the virtual human in all conditions. Unlike Thaler et al. [66], who found no significant impact of a personalized body shape on body weight perception but in line with Piryankova et al. [52], who found a small influence, the personalized body shape across conditions might explain the observed correlations in our study. Future research should investigate the influence of personalizing a virtual human's body shape on body weight estimations to determine whether there is a consistent influence of individual BMI on body weight estimation.

We further noted significant correlations between participants' BMI and the difference between their body's actual BMI and the virtual human's BMI (i.e., the body weight modification level) in PET measures. Participants were most accurate when the virtual human's body weight closely matched theirs. For PET $\overline{M}$, participants consistently overestimated the virtual human's body weight across all conditions when it was lower than theirs and underestimated it when it was higher (see Fig. 7, top). As also observed by Döllinger et al. [18], the misestimations became more inaccurate with decreasing body weight than with increasing body weight, potentially contradicting Weber's law [10, 28]. However, the general pattern aligns with the contraction bias [9, 10], where individuals subconsciously anchor their body weight estimations to a reference template. This reference template in our study was possibly around their actual BMI. For PET $\overline{A}$, the body weight estimation accuracy decreased with deviating body weight modification level (see Fig. 7, bottom), showing the most accurate estimations consistently at 0 % and +10 %. Interestingly, while 0 % reflects the average BMI of the sample (23.02), +10 % approximates the average BMI of the local population (26). It suggests that another reference template could be anchored around the average BMI of the population. However, future work needs to investigate this observation in more detail.

In summary, participants' BMI influenced the body weight estimations across all conditions, indicating the presence of a contraction bias. This result suggests that an individual's BMI consistently affects the body weight estimation of virtual humans. Hence, future work on body weight perception should always consider their users' BMI when employing body weight estimation tasks.

5.4 Self-Esteem and Body Shape Concerns Influence Body Weight Perception

We examined the interplay between self-esteem, body shape concerns, and body weight perception on an exploratory basis. The results showed a significant correlation between participants' self-esteem and PET $\overline{M}$. Moreover, body shape concerns correlated significantly with AMT current and AMT ideal. Additionally, body shape concerns and the embodiment factor significantly impacted misestimations of virtual humans for AMT current. Participants with lower body shape concerns tended to underestimate avatars but accurately estimated agents. Those with higher concerns tended to overestimate both. Hence, our results contrast the findings of Thaler et al. [67], who showed no influences of self-esteem and body shape concerns on body weight perception of virtual humans. Following Cash and Deagle [8], we consider body shape concerns as an attitudinal factor influencing body perception, especially when one identifies strongly with the perceived body. Consequently, the embodiment factor is pivotal in determining whether participants view the virtual human as themselves or as a distinct being.

In summary, our findings support the assumption that body perception involves perceptual and attitudinal components [8,32]. They further indicate the use of double standards between avatars and agents, similar to the distinction between self and others in prior work [72,73]. Furthermore, they support assumptions of prior work [47] that individuals can estimate agents more neutral without negative attitudes. These insights could be utilized in designing applications supporting body perception, where personalized agents may foster a positive body perception. Additionally, they support previous assumptions that self-esteem and body shape concerns are associated with body image distortions [38, 49].

5.5 Limitations and Future Work

Our study provides valuable insights on how virtual human embodiment and personalization impact body perception in VR. However, we have identified limitations and areas for future research. Firstly, our body weight modification method alters the virtual human's body shape but does not affect the texture, leaving cues like skin and fabric folds or bone protuberances unchanged. Future research should explore techniques to modify texture in addition to the shape.

Secondly, our manipulation of embodiment required us to personalize the body shape of virtual humans to maintain the same body height in all conditions. As described by Wolf et al. [78], manipulating the height of a truly generic virtual human to the participants' body height would change the virtual human's body volume/weight, leading to inaccurate body weight estimations. Hence, future work should incorporate a manipulation of body height into their body modification model to investigate the influence of body shape personalization in conjunction with embodiment.

Thirdly, our results are tied to VR experiences, where users' bodily awareness could be negatively affected [16]. However, virtual humans can also be part of less immersive augmented reality (AR) applications, where research on their embodiment [27, 79] and use as virtual agents [76] has recently accelerated. Hence, future work should investigate how embodiment and personalization impact scenarios in AR, where the real body is visually present.

Fourthly, the ethnic mismatch between participants and the exclusively white generic virtual humans could have a minor impact on the variance of our results. Recent research by Do et al. [15], only published after we conducted our study, highlights the importance of addressing ethnic diversity in future work.

Lastly, in our non-embodiment condition, participants lacked a virtual body. We showed only their controller to eliminate ambiguity between a potential virtual body and the agent's body. Hence, future work should investigate the effects of the own virtual body when evaluating the virtual bodies of agents.

6 Conclusion and Contribution

Our work showed that designing virtual humans with self-related cues through personalization and embodiment influences their perception in VR. In detail, it revealed that both factors have a strong separate and complimentary influence on SoE and self-identification, leading to the highest scores when both are employed together. In the context of body weight perception, the influence of personalization and embodiment varies depending on the specific body weight modification and estimation task. Our findings suggest that double standards can occur in the body weight estimation of virtual humans when utilized with self-related cues, mainly through the embodiment of the virtual human. Furthermore, the users' individual BMI consistently predicted their body weight estimations following the principle of the contraction bias. In addition, our exploratory analysis establishes correlations between self-esteem and body shape concerns with body weight perception, further supporting the existence of double standards in body weight perception. In summary, our research demonstrates the complex interplay between embodiment, personalization, the individual's BMI, and attitudinal components in shaping the body weight perception of virtual humans. Understanding these factors is crucial for designing compelling virtual experiences, whether addressing body shape concerns or treating body-related disorders using virtual humans. This knowledge further contributes to our understanding of human body perception and sheds light on how we perceive virtual humans within VR.

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