Alpha IVBO - Construction of a Scale to Measure the Illusion of Virtual Body Ownership

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Abstract
In this paper, we present a scale construction and its initial test as a step towards a standardized measure of the illusion of virtual body ownership (IVBO) in virtual simulations. The IVBO describes the effect of users partly or fully perceiving a virtual body as their own. We analyzed components for a scale we call "Alpha IVBO" by using data from a fake mirror scenario study. Users saw their movements mapped in real-time to a virtual avatar rendered on 3D display placed in front of them. The principal component analysis of our sample data resulted in three factors: *"acceptance"*, *"control"* and *"change"*.

Author Keywords
Embodiment, Virtual Body Ownership, Avatars

ACM Classification Keywords
H5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities

Introduction
From RHI to IVBO
The illusion of body ownership (IBO) gained continuous attention in current Human-Computer Interaction and Virtual Reality (VR) research, concentrating on the phenomenon induced in virtual simulations, the so called illusion of virtual body ownership [20]. The underlying phenomenon was

originally discovered by Botvinick and Cohen in 1998 [5], known as the "rubber-hand illusion" (RHI, see [26] for a review). Following multiple studies investigating aspects of IBO, a model describing bottom-up processes through multisensory integration (e.g. visuo-tactile synchrony, visouo-motor synchrony) in addition to top-down processes (e.g. similarity of form and appearance) modulating these bottom up factors was proposed [31, 30]. Recent studies gave more insights into the origins of IBO using virtual environments and VR, due to the high degree of freedom in manipulation and experimental control. The following paragraphs aim at disentangling potential subcomponents of the IVBO.

Botvinick and Cohen [5] found significant responses in the items: *"It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand-touched"*, *"It seemed as though the touch I felt was caused by the paintprush touching the rubber hand"*, and *"I felt as if the rubber hand were my hand"*.

Relation to Agency and Control
Tsakiris and colleagues found that the perception of IBO is strongly linked to agency, which is "responsible for the coherence of body ownership" [32, p. 431], and further conclude that "bodily self-consciousness comes from action, and not from sensation." [32, p. 431]. Similar to the original RHI experiment, they utilized the users' perception of body part displacement (proprioceptive drift), often used as (cross-validating) implicit measure for IBO [5, 31, 15, 8]. In relation to the coherence of avatar control, Waltemate and colleagues found that increasing latency between action and visual feedback decreases motor performance and perceived simultaneity at 75ms whereas the perceived IBO and agency significantly start to decrease between 125ms and 210ms [33]. Kalckert and Ehrsson investigated the potential interactions between body ownership and agency, and found first implications for a dissociation between the factors [15].

Self-perception, Self-Attribution and Functionality
Aymerich-Franch and Ganesh summarize multiple studies related to (artificial) body part/object appearance in relation to self-perception and self-attribution. Although findings are diverse, object appearance and affordance seem to modulate ownership in a top-down constraint but are not sufficient for ownership illusions [2, 21] They therefore argue for a model driven by functional affordance of the artificial body part [2]. Homuncular flexibility, an idea by Lanier and colleagues, was recently further investigated by Won and colleagues [35]. Users were represented by avatars switching or extending users' limb movements or avatars incorporating an additional third arm. They found that users rapidly adapted to the novel body schema and could not find any significant differences in their presence measures that related to ownership.

Body Change and Behavioral Impact
Yee and Bailenson found relations between the IVBO and perceived body change. Closely related to the SIDE Model [28] as well as the newer virtual "doppelgänger" model [10, 11], the *proteus effect* [36] describes the change in behavior, self-perception and identity of users (from their "self") towards behavior and identity they attribute to their avatar, which they confirmed for attractiveness and height. Further confirmation of effects of body change were found for child-avatars and over-estimation of size [4], stereotypical biases towards race [13, 22], and the perception of environment steepness [37].

The Request for a Standardized Measure
To our knowledge, a standardized and validated scale to assess the illusion of virtual body ownership does not exist. Reviewing the literature, we found that previous measures are often situation-specific and reliabilities are seldom reported, which reduces the comparability of the results. More importantly, effects are often assessed with a set of single items, which is problematic when analyzed individually [6]. Although various cross-validating measures have been applied, the validation often failed ([16] summarizes

Critical oral questions used by Gonzalez-Franco and colleagues: *"I felt as if the body I saw in the mirror might be my body"*, and *"I had the feeling that I might be harmed if I collided with the air fan"*. Consistency checks: *"The movements I saw the body in the mirror make seemed to be my movement"*,*"The body I saw in the mirror was another person"*, and *"I felt as if my real body were floating above the ground"*.

measures for IBO and IVBO). It was therefore our objective to target this problem by contributing with the construction of a scale that can be applied to different experimental designs in capturing the IVBO. In this paper, we summarize previous approaches for the evaluation of the IBO as the basis of our item selection, followed by the analysis of recent data, to investigate the structure of the IVBO in more depth and find its underlying components. Our goal was to develop a validated measurement for latent variables and to examine the structure of body ownership illusions in virtual environments focusing on visual representation and control in a first step. In our evaluation we used a fake virtual mirror scenario, manipulating avatar appearances. In the following we briefly review related work that inspired the scale construction, followed by our approach and the scale proposal as well as a critical discussion.

Related Measures

Botvinick and Cohens Measures
Originally exploring the RHI, Botvinick and Cohen used a seven-step visual-analogue scale ('disagree strongly','agree strongly') to assess nine statements [5]. Their cross-validating measure was perceptual displacement. Out of the nine items, three questions evoked significant affirmative responses ($p's < .018$) [5, p. 756] validating the results from the perceptual displacement measure.

Perspective
Slater and colleagues investigated the impact of first-person and third-person perspective on IVBO. Male subjects were immersed in VR, represented by a female avatar [27]. They analyzed heart rate deceleration and cross-validated the results with a 13-item questionnaire related to *body ownership* and *agency* derived from piloting and literature [5, 18, 7]. Questions assessed for example how strong the subject felt the virtual body was his/her body or how strong the feeling was looking at "yourself". A 10-point scale ('not at all', 'very much') was used [27, p. 8]. Their results state that first-person perspective is a crucial factor for the IVBO which was confirmed by a second study also investigating Avatar appearance [21].

Appearance
Maselli and colleagues assessed the structure of the IBO by a systematic manipulation of visuotactile and visual sensorimotor contingencies, visual perspective, and avatar appearance [21]. Their questionnaire included 7 items, categorized in ownership, psychophysical reaction, interaction in VR, implementation, and control assessed by an 8-point Likert scale ('not at all','very much'). A cross-validating measure (heart-rate deceleration) did not reveal notable correlations. Their results state that full IVBO can be affected by avatar realism and as well as congruency/inconcruency of sensuomotor contingencies (see [21, p. 13] for their model).

Mirror Reflections
Assessing real-mirror reflections, Gonzalez-Franco and colleagues used an oral questionnaire read out to participants after two different conditions (synchronous, asynchronous) [12]. Participants were asked to answer on a scale ranging from 1-5 ('disagree strongly','agree strongly') to five questions of which two were critical and three were consistency checks. Their implicit cross-validating measure was the proportion of time the participant moved the virtual avatar below the virtual fan (threat). The authors found higher IVBO in a synchronous condition and suspected agency to be a contributing factor whereas co-location and visuo-tactile synchrony seem to be dominant [12].

A First Psychometric Approach
In a non-virtual environment study, Longo and colleagues provided a first approach to utilize psychometry to mea-

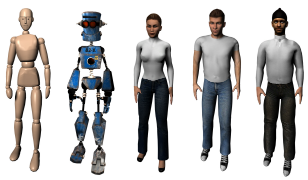

Figure 1: A wooden mannequin, a robot, a male/female generic human as well as an individualized avatar based on subject scans was used to explore the effect of anthropomorphism for the IVBO. During the study, the avatar eyes were covered by sunglasses, similar to the real scenario where the user had to wear passive stereo glasses.

sure IBO [19]. They measured perceptual displacement along with a 27 items 7-point Likert scale questionnaire (strongly agreed - strongly disagreed). In their PCA results, they found four components accounting for 55.3% of the dataset variance: *"embodiment of rubber hand"*, *"loss of own hand"*, *"movement"*, and *"affect"*. Further investigating the *"embodiment of rubber hand"* component, a PCA based on items loading moderate-strong on this component, they found the three factors *"location"*, *"ownership"*, and *"agency"*. In their ownership factor, items were related to the rubber hand being part of one's own body.

Embodiment of a Robot - In Situation Measurement
Aymerich-Franch and colleagues utilized three items from [16] in a short in-situ oral questionnaire on a 7-point Likert scale ('not at all', 'very strongly'). The experimenter therefore asked the subjects during the induction if they were feeling as if "the robots body was your own body", "you were located in the position of the robot", "You could use the robot's body to push objects near you" [3]. Although using only 3 items to assess the factor, the scale reliability was good ($\alpha = .89$).

Approach and Scale Construction

Based on our review, we extended a previous scale used in [20] that adapted questions from [27, 29, 23, 7, 1] with additional items from [27, 15, 12, 24], see table 1. The instrument included items that stand in perceptual relation of the virtual body, items measuring the effects of control, as well as items that relate to the self-perception and after-effects. In addition, we included an item to define perceived human-likeness, as appearance realism was also found to be a contributing factor to IVBO [21]. We excluded questions related to a *threat*, which was not included in the main part of the experiment. Similarly, we did not induce *tactile sensation*. Arguments have been made that perspective and postural identity can by themselves lead to the induction of IVBO [21]. Furthermore, despite the findings that IBO is related to *"location"*, we found items related to location might not directly describe the IBO as such, rather then the effects of self-presence, and physical presence. There are valid existent scales available for these phenomena [25, 34].

Exploratory Evaluation
In our experiment, the study goal was to investigate avatar's anthropomorphism in relation to the IVBO. In a low-immersive setup consisting of a "fishtank" like VR simulation using a passive 3D screen, subjects were tracked by a Microsoft Kinect One and depth sensor for facial expression tracking. In a within-subjects design, participants ($N = 43$) were represented in a "fake mirror" scenario by four different avatars leading to four trials of about one minute each in randomized order. Participants were instructed to explore their virtual mirrored image by performing a defined set of body movements, facial expressions, or focus on certain objects. After each trial, the scale questionnaire was filled out digitally by the participants using a 7-point Likert scale (strongly disagree - neither agree or disagree - strongly agree). The study details and results are described in [17].

Analysis
Similar to [19], we used a PCA to identify the underlying structure of IVBO. We followed the procedure described in [9], using a Varimax orthogonal rotation. We conducted four individual PCAs for each score-set. Although visual analysis of the scree plots pointed towards reducing to two components, we stuck to the criterion of Kaiser [14] due to the small sample size. Therefore, only components with Eigenvalues < 1 were discarded. Kaiser-Mayer-Olkin Measures of sample adequacy for the four calculations were $> .641$, all Bartlett's tests for sphericity were significant.

Table 1: The proposed Alpha IVBO scale extended from [20], with the three subcomponents Acceptance, Control and Change to measure IVBO. We discarded item 14 and 15 due to insufficient component loading and consistency. In the evaluation, the scale was presented with a 7-Point Likert response format (strongly disagree - neither agree or disagree - strongly agree), the question order was randomized. The instructions read "Please answer the following questions according to your gut feeling, spontaneously and intuitively.

	item	Question
Acceptance	1. myBody	I felt as if the body I saw in the virtual mirror might be my body. *Adapted from* [27, 12]
	2. myBodyParts	I felt as if the body parts I looked upon where my body parts. *Adapted from* [15]
	3. humanness	The virtual body I saw was humanlike. *Adapted from* [24]
Control	4. myMovement	The movements I saw in the virtual mirror make seemed to be my own movements.
	5. bodyControlEnjoyment	I enjoyed controlling the virtual body I saw in the virtual mirror.
	6. controlMovements	I felt as if I was controlling the movement I saw in the virtual mirror. *Adapted from* [15]
	7. causeMovements	I felt as if I was causing the movement I saw in the virtual mirror. *Adapted from* [15]
Change	8. ownOtherbody	The illusion of owning a different body than my real one was very strong during the experience.
	9. myBodyChange	At a time during the experiment I felt as if my real body changed in its shape, and/or texture.
	10. myBodyCheck	During or after the task, I felt the need to check that my body does really still look like to what I had in mind.
	11. echoHeavyLight	I felt an after-effect as if my body had become lighter/heavier.
	12. echo-Tall-Small	I felt an after-effect as if my body had become taller/smaller.
	13. echo-LargeThin	I felt an after-effect as if my body had become larger/thinner.
Excluded	14. *otherPerson*	*The body I saw in the mirror was another person. Adapted from* [12]
	15. *enjoyment*	*How did you like the overall experience in the virtual world?*

	AC	CO	CH
Woodie	.857	.905	.859
Robot	.773	.899	.853
Human	.787	.839	.872
Custom	.886	.887	.817

Table 2: Reliabilities (Cronbach's α) of the components Acceptance (AC), Control (CO), and Change (CH), tested against the scores of the individual trials in the experiment.

Results

The results of the exploratory PCA are depicted in table 3. In three of the four conditions, we found constructs of three components we named: *"acceptance"*(AC) , *"control"* (CO), and *"change"* (CH). This resulted in our final scale proposal (see table 1). *"Acceptance"* inherits items related to self-attribution and accepting the virtual body body parts as the own body parts. *"Control"* inherits items that relate to agency and the appropriate visual feedback of motion control. The component *"change"* is comprised of items that measure changes in self-perception. The *"change"* and *"control"* component explained over 50% of the variance in all trial analysis, wheras acceptance only explained around 10% of the variance. In our study *control* was not manipulated systematically during the experiment, the loadings however indicate confirmation of the findings in literature on the strong impact of bottom-up processes and the relation to agency [31, 30, 20]. The reliabilities of the scale according to the components found are quite high as depicted in table 2. Different items did not structure the way we hypothesized. First, the item *ownOtherBody* which we hypothesized would directly related to the acceptance or ownership of another body did only load on the *acceptance* component (AC) in two of the 4 analyses, and in addition, the load was rather low. A second surprise was that the item *humanness* loaded onto the acceptance component. Although not stable in the "generic human" avatar trial, it correlated with the two other acceptance items *myBody* and *myBodyParts*. Interestingly, the item "otherPerson" did not load distinctly on one component. One interpretation of this finding surrounds the idea that the concept "person" might not be adequate when testing for ownership.

Table 3: PCA results for the conditions (item relations $< .4$ are not displayed)

Avatar Trial	Woodie			Robot			Human			Individualized			
Concept	CH	CO	AC	CH	CO	AC	CH	CO	AC	CH	CO	AC	misc
myBody			.908			.869			.848			.922	
ownOtherBody	.497			.522		.477	.628		.486	.427			-.641
myBodyParts			.875			.790			.895			.905	
myMovements		.850			.864			.737			.820		
bodyControlEnjoyment		.841			.776			.819			.819		
controlMovements		.918			.912			.858			.879		
causeMovements		.873			.866			.851			.868		
myBodyChange	.864			.829			.699			.854			
myBodyCheck	.565			.741			.683			.422			.775
echoHeavyLight	.928			.941			.796			.865			
humanness			.725			.707		.612	.428			.739	
echoTallSmall	.837			.771			.867			.870			
echoLargeThin	.839			.843			.923			.911			
Variance Explained Init. (%)	35.6	26.5	11.7	36.4	23.8	11.5	35.3	25.8	10.2	34.3	26.5	10.6	8.0
Variance Explained Rot.(%)	29.1	24.7	20.3	29.1	24.0	18.5	28.8	24.8	17.7	26.8	24.7	19.3	8.7
Initial Eigenvalue	4.67	3.45	1.52	4.73	3.09	1.49	4.59	3.35	1.33	4.47	3.44	1.38	1.04
Eigenvalue After Rot.	3.79	3.21	2.64	3.79	3.12	2.40	3.74	3.22	2.30	3.48	3.21	2.51	1.13

Discussion and Conclusion

In a conceptual review Kilteni and colleagues provide a working definition of the sense of embodiment and describe it as *"ensemble of sensations that arise in conjunction with being inside, having, and controlling a body"* [16, p. 374f] and point out the lack of a standardized measure. In this paper, we reviewed related literature that inspired the construction of a scale to measure IVBO. We analysed our study dataset using a PCA and found components that we defined as *acceptance*, *control*, and *change*. The proposed scale seems robust within our data. However, this scale is still work in progress, and results should not be blindly generalized. Considering limitations, it is notable that we assessed data in a within-subject design and the sample size was relatively small. However, this initial approach can make a strong contribution and act as point of discussion within the community toward a standardized measure for assessing the IVBO, as it is constructed to be a more uniform assessment tool independent of the given apparatus. The scale can be used by practitioners using a 7-point Likert response format. As the construction only relates to visual feedback and perception, the scale adapts to multiple experimental scenarios. Future replications shall include the validation using an immersive HMD and test correlations to similar constructs. We hypothesize that the usage of a HMD will increase *control* and *change* scores. Furthermore the coherence of perspective toward a whole virtual body, which we could not induce with the fake mirror, should modulate *acceptance*. We aim at cross-validating the results of further scale developments with proprioceptive drift measurements or physiological measures.

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References

[1] K. Carrie Armel and Vilayanur S. Ramachandran. 2003. Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society of London B: Biological Sciences* 270, 1523 (2003), 1499–1506.

[2] Laura Aymerich-Franch and Gowrishankar Ganesh. 2016. The role of functionality in the body model for self-attribution. *Neuroscience Research* 104 (2016), 31–37.

[3] Laura Aymerich-Franch, Damien Petit, Gowrishankar Ganesh, and Abderrahmane Kheddar. 2015. Embodiment of a humanoid robot is preserved during partial and delayed control. In *2015 IEEE International Workshop on Advanced Robotics and its Social Impacts*.

[4] D. Banakou, R. Groten, and M. Slater. 2013. Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences* 110, 31 (July 2013), 12846–12851.

[5] Matthew Botvinick, Jonathan Cohen, and others. 1998. Rubber hands' feel'touch that eyes see. *Nature* 391, 6669 (1998), 756–756.

[6] James Carifio and Rocco J. Perla. 2007. Ten common misunderstandings, misconceptions, persistent myths and urban legends about Likert scales and Likert response formats and their antidotes. *Journal of Social Sciences* 3, 3 (2007), 106–116.

[7] H. Henrik Ehrsson. 2007. The experimental induction of out-of-body experiences. *Science* 317, 5841 (2007), 1048–1048.

[8] Harry Farmer, Ana Tajadura-JimÃĺnez, and Manos Tsakiris. 2012. Beyond the colour of my skin: how skin colour affects the sense of body-ownership. *Consciousness and Cognition* 21, 3 (2012), 1242–56.

[9] Andy P. Field. 2009. *Discovering statistics using SPSS: (and sex, drugs and rock 'n' roll)* (3rd ed ed.). SAGE Publications, Los Angeles.

[10] Jesse Fox, Jeremy Bailenson, and Joseph Binney. 2009. Virtual experiences, physical behaviors: The effect of presence on imitation of an eating avatar. *Presence: Teleoperators and Virtual Environments* 18, 4 (2009), 294–303.

[11] Jesse Fox and Jeremy N. Bailenson. 2009. Virtual self-modeling: The effects of vicarious reinforcement and identification on exercise behaviors. *Media Psychology* 12, 1 (2009), 1–25.

[12] Mar Gonzalez-Franco, Daniel Perez-Marcos, Bernhard Spanlang, and Mel Slater. 2010. The contribution of real-time mirror reflections of motor actions on virtual body ownership in an immersive virtual environment. In *2010 IEEE virtual reality conference (VR)*. IEEE, 111–114.

[13] Victoria Groom, Jeremy N. Bailenson, and Clifford Nass. 2009. The influence of racial embodiment on racial bias in immersive virtual environments. *Social Influence* 4, 3 (July 2009), 231–248.

[14] Henry F. Kaiser. 1960. The application of electronic computers to factor analysis. *Educational and psychological measurement* (1960).

[15] Andreas Kalckert and H. Henrik Ehrsson. 2012. Moving a rubber hand that feels like your own: a dissociation of ownership and agency. *Frontiers in human neuroscience* 6 (2012).

[16] Konstantina Kilteni, Raphaela Groten, and Mel Slater. 2012. The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments* 21, 4 (2012), 373–387.

[17] Marc Erich Latoschik, Jean-Luc Lugrin, and Daniel Roth. 2016. FakeMi: a fake mirror system for avatar embodiment studies. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology*. ACM, 73–76.

[18] Bigna Lenggenhager, Tej Tadi, Thomas Metzinger, and Olaf Blanke. 2007. Video ergo sum: manipulating bodily self-consciousness. *Science* 317, 5841 (2007), 1096–1099.

[19] Matthew R. Longo, Friederike Schüür, Marjolein P.M. Kammers, Manos Tsakiris, and Patrick Haggard. 2008. What is embodiment? A psychometric approach. *Cognition* 107, 3 (June 2008), 978–998.

[20] Jean-Luc Lugrin, Johanna Latt, and Marc Erich Latoschik. 2015. Anthropomorphism and Illusion of Virtual Body Ownership. In *International Conference on Artificial Reality and Telexistence Eurographics Symposium on Virtual Environments*.

[21] Antonella Maselli and Mel Slater. 2013. The building blocks of the full body ownership illusion. *Frontiers in human neuroscience* 7 (2013).

[22] Tabitha C. Peck, Sofia Seinfeld, Salvatore M. Aglioti, and Mel Slater. 2013. Putting yourself in the skin of a black avatar reduces implicit racial bias. *Consciousness and cognition* 22, 3 (2013), 779–787.

[23] Valeria I. Petkova and H. Henrik Ehrsson. 2008. If I were you: perceptual illusion of body swapping. *PloS one* 3, 12 (2008), e3832.

[24] Aaron Powers and Sara Kiesler. 2006. The advisor robot: tracing people's mental model from a robot's physical attributes. In *Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*. ACM, 218–225.

[25] Rabindra Ratan and Beatrice Hasler. 2009. Self-presence standardized: Introducing the self-presence questionnaire (SPQ). In *Proceedings of the 12th Annual International Workshop on Presence*.

[26] Mel Slater, Daniel Perez-Marcos, Henrik Ehrsson, and Maria V. Sanchez-Vives. 2009. Inducing illusory ownership of a virtual body. *Frontiers in Neuroscience* 3 (2009).

[27] M. Slater, B. Spanlang, M. V. Sanchez-Vives, O. Blanke, and Mark A. Williams. 2010. First Person Experience of Body Transfer in Virtual Reality. *PLoS ONE* 5, 5 (2010), e10564.

[28] Russell Spears and Martin Lea. 1994. Panacea or panopticon? The hidden power in computer-mediated communication. *Communication Research* 21, 4 (1994), 427–459.

[29] William Steptoe, Anthony Steed, and Mel Slater. 2013. Human tails: ownership and control of extended humanoid avatars. *IEEE transactions on visualization and computer graphics* 19, 4 (2013), 583–590.

[30] Manos Tsakiris. 2010. My body in the brain: a neurocognitive model of body-ownership. *Neuropsychologia* 48, 3 (2010), 703–712.

[31] Manos Tsakiris and Patrick Haggard. 2005. The rubber hand illusion revisited: visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance* 31, 1 (2005), 80.

[32] Manos Tsakiris, Gita Prabhu, and Patrick Haggard. 2006. Having a body versus moving your body: How agency structures body-ownership. *Consciousness and cognition* 15, 2 (2006), 423–432.

[33] Thomas Waltemate, Irena Senna, Felix Hülsmann, Marieke Rohde, Stefan Kopp, Marc Ernst, and Mario Botsch. 2016. The Impact of Latency on Perceptual Judgments and Motor Performance in Closed-loop Interaction in Virtual Reality. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology*. München.

[34] Bob G. Witmer and Michael J. Singer. 1998. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments* 7, 3 (1998), 225–240. bibtex:Witmer1998.

[35] Andrea Stevenson Won, Jeremy Bailenson, Jimmy Lee, and Jaron Lanier. 2015. Homuncular flexibility in virtual reality. *Journal of Computer-Mediated Communication* 20, 3 (2015), 241–259.

[36] Nick Yee and Jeremy Bailenson. 2007. The Proteus effect: The effect of transformed self-representation on behavior. *Human communication research* 33, 3 (2007), 271–290.

[37] Sangseok You and S. Shyam Sundar. 2013. I Feel For My Avatar: Embodied Perception in VEs. (2013).