Designing Self-presence in Immersive Virtual Reality to Improve Cognitive Performance—A Research Proposal

Katharina Jahn, Bastian Kordyaka, Caroline Ressing, Kristina Roeding and Bjoern Niehaves

Abstract With the increasing availability of immersive virtual reality (IVR) technologies, new opportunities to change individuals' behavior become possible. Notably, recent research showed that by creating a full-body ownership illusion of a virtual avatar looking similar to Einstein, users' cognitive performance can be enhanced. However, although research is quite consistent in reporting that visuomotor synchrony in IVR achieved with body tracking suffices to elicit body ownership illusions that change behavior, it is still unclear whether strengthening these visuomotor illusions with additional technological design elements, such as visuotactile feedback, can contribute to increase desired outcomes even more. In this research in progress paper, we aim to conduct a 2 (physical feedback: low vs. high) × 2 (avatar design: normal vs. high intelligence) between-subjects experiment in IVR to test this assumption. In addition to subjective measures, we use heart rate and electrodermal activity to assess the strength of self-presence induced through the illusions.

Keywords Body ownership illusions · Heart rate · Electrodermal activity · Cognitive performance · Physical feedback

---

K. Jahn (✉) · B. Kordyaka · C. Ressing · K. Roeding · B. Niehaves
University of Siegen, Chair of Information Systems, Siegen, Germany
e-mail: katharina.jahn@uni-siegen.de

B. Kordyaka
e-mail: bastian.kordyaka@uni-siegen.de

C. Ressing
e-mail: caroline.ressing@uni-siegen.de

K. Roeding
e-mail: kristina.roeding@uni-siegen.de

B. Niehaves
e-mail: bjoern.niehaves@uni-siegen.de

F. D. Davis et al. (eds.), *Information Systems and Neuroscience*,
Lecture Notes in Information Systems and Organisation 32,
https://doi.org/10.1007/978-3-030-28144-1_9

1 Introduction

With the ability to present user's visual, auditory, and tactile senses with completely virtual content, Immersive Virtual Reality (IVR) provides new opportunities to represent the bodily self of users. IVR describes a set of technologies that, by enclosing the user with head-mounted displays (HMD) or cage systems heightens sensory immersion. Sensory immersion is a characteristic of the technology, which is high when users are separated into a technology from the real world and their real movements are matched to the virtual environment [1]. In contrast to this technological viewpoint, the sense of telepresence describes the psychological perception of the "illusion of being in a distant place" or "being there" of the individual, [2, p. 438], which should arise in individuals when technology provides a high degree of sensory immersion.

In IVR, full-body ownership illusions can be created by combining HMDs with full-body tracking, creating a high degree of self-presence [2]. Self-presence relates to the "Illusion [of] inhabiting the virtual body" [2, p. 438], when interacting with a virtual body in an environment. Self-presence elicited through body ownership illusions arises when the users' real movements are tracked in real-time and then transferred to a virtual body in the IVR. As a result, the movements of the users' virtual body are displayed in synchrony to the users' real body movements (visuomotor synchrony). This synchrony is sufficient for individuals to experience self-presence [3]. However, when design elements such as visuotactile or visuomotor synchrony are disrupted, self-presence can be diminished [4].

Research already showed, that self-presence created by full-body ownership illusions offer many opportunities to enhance desired behavioral and cognitive outcomes when working alone or interacting with other people. As an example, individuals embodied in a virtual body with dark skin drum differently [5] and show decreased racial bias and prejudice [6, 7] compared to individuals in a virtual body with white skin. Additionally, individuals embodied in the body of Sigmund Freud show different cognitive processing of problems [8]. Furthermore, full-body ownership illusions can even change male users' cognitive performance if they are embodied in an avatar that is associated with high intelligence [9].

Whereas a main factor to elicit full-body ownership illusions with sufficient strength seems to be first person perspective, the strength of body ownership illusions is dependent upon multiple factors. Research has indicated that the strength of body ownership illusions is related to questionnaire items, but can also be measured by biophysiological variables, for example through skin conductance response or heart rate in reaction to a threat [4, 10, 11]. However, whether increasing the effectivity of the body ownership illusions through specific design elements to enhance the cognitive or behavioral outcomes induced through a specific avatar design, is still unclear. Therefore, we want to investigate the following research question to contribute to close this research gap:

RQ: How can the interaction between users and virtual avatars be designed to increase users' self-presence and cognitive performance in immersive virtual realities?

To answer our research question, we plan to conduct a 2 (physical feedback: low vs. high) × 2 (avatar design: normal vs. high intelligence) between-subjects experiment.

2 Background and Research Model

In this section, we develop our hypotheses based on literature on the antecedents and outcomes of self-presence through full-body ownership illusions. Our research model is displayed in Fig. 1, which we explain in the following paragraphs.

2.1 Full-Body Ownership Illusions and Effects on the Self

Rooted in the classical rubber hand illusion experiment [12], in which a rubber hand is touched in synchrony with the individuals' real hand, subsequently arising a sense of ownership over the rubber hand, full-body ownership illusions elicit a sense of ownership over a complete body [3, 13]. When IVR is used with body tracking, these illusions can create a quite realistic experience of having another body.

From a theoretical point of view, self-presence initiated through body ownership illusions constitutes a passive form of perspective taking [14, 15], in which, rather than imagining to be in the shoes of another person, users can directly experience owning another body [9, 16]. As a consequence, if full-body ownership illusions arise for avatars with specific design elements (e.g. skin color or similarity to a person with competencies in a specific area), individuals cognitive processing and behavior can be influenced [6, 17]. It is assumed that this process occurs by activating existing resources of the individual previously not accessible through this form of perspective-

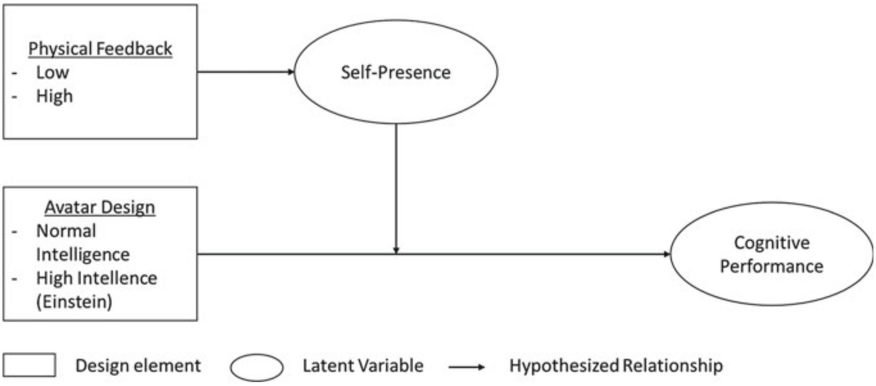

Fig. 1 Research model

taking [8, 9]. For example, when individuals were embodied in a virtual avatar of Sigmund Freud when they counselled themselves, they showed more positive mood changes than when they were embodied in a body-scanned version of themselves [8]. Additionally, individuals who are embodied in an avatar of Einstein show higher performance outcomes in a cognitive task than when they are embodied in a regular unknown body with which they most likely connect lower intelligence levels [9]. We therefore hypothesize that:

Hypothesis 1. Being embodied in a virtual body that is associated with high intelligence leads to higher cognitive performance than being embodied in a virtual body that is associated with normal intelligence.

2.2 Strength of Self-presence

Previous research on virtual arms has indicated that self-presence can be induced by synchronous visuomotor stimulation, even when tactile stimulation is absent [10]. Comparing the effects of visuomotor and visuotactile interaction has shown that the disruption of visuotactile synchrony leads to a lower body ownership illusion [4]. Thus, we suspect that sustaining congruence for visual stimuli coming in contact to the body and touch that is subsequently felt is highly important for keeping the level of self-presence high. This should be especially important in situations in which users have to interact with their hand's multiple times in fine granularity, as this is the case with many virtual reality applications. However, when users' bodies are fully tracked, including their fingers, physical feedback can be incomplete after interaction with virtual objects if no feedback mechanism is implemented in addition to the tracking device. Therefore, we assume that self-presence is higher when physical feedback is presented, and, that, this strengthened self-presence leads to an increased effect of avatar design on cognitive performance.

Hypothesis 2. High physical feedback leads to higher self-presence than low physical feedback.

Hypothesis 3. Self-presence strengthens the effect avatar design has on cognitive performance.

2.3 Relation of Self-presence to Biophysiological Measures

The level of users' self-reported self-presence seems to be related to biophysiological measures after a threat to the integrity of the virtual body occurs, with the strength of self-presence influencing the strength of the biophysiological reactions to the threat [3]. Sliding a knife over the artificial body increases electrodermal activity compared to a spoon or asynchronous physical feedback [18] and a knife sliding over the body in a condition of first person perspective with synchronous physical feedback results in higher electrodermal activity than a third person perspective or asynchronous physical feedback [19]. In both related studies, these differences were also reflected by the questionnaire items for self-presence. However, other research indicated that synchronous and asynchronous physical feedback is not necessarily reflected by a change in skin conductance response [4]. To gain more insights into these effects, we hypothesize:

Hypothesis 4. Higher levels of self-presence are reflected by an increase in electrodermal activity after the presentation of a threat to the virtual body.

Another biophysiological measure that has been shown to be related to self-presence is heart rate deceleration. After seeing a woman slapping the face of a virtual body from a first person perspective, heart rate deceleration increased compared to a third person perspective, which was also related to the questionnaire items for self-presence [20]. Additionally, heart rate deceleration is positively related to self-reported self-presence in a questionnaire after the legs of the virtual body were visually separated [3]. Thus, we hypothesize:

Hypothesis 5. Higher levels of self-presence are reflected by an increase in heart rate deceleration after the presentation of a threat to the virtual body.

3 Method

3.1 Participants and Design

We will recruit at least 128 male participants to take part in our experiment and use a 2 (physical feedback: low vs. high) × 2 (avatar design: normal vs. high intelligence) between-subjects design to test our hypotheses.

3.2 Materials and Measures

IVR: A HTC Vive HMD will be used to display the virtual environment, which will be designed with Unity 3D. Full-body tracking will be implemented with five HTC Vive trackers (2 for hands, 2 for feet, 1 for hip) and hand-tracking will be implemented by using Hi5 VR Gloves. Avatars are created using Adobe Fuse.

Electrodermal Activity. We will use electrodermal activity (EDA) as a biophysiological measure for self-presence. In line with previous research in the area of body ownership illusions, EDA will be measured in the 6 s baseline period and in 2–8 s period after the threat [4]. The latency window during which a response will be assumed to be elicited by the stimulus will be based on frequency distributions of response latencies to simple stimuli (1–4 s) [21].

Heart Rate. We will use the Polar H7 belt to measure participants' heart rate deceleration. In line with previous research, we will measure the mean heart rate for a baseline period of six seconds before and six seconds after the presentation of a threat [4, 22]. As dependent variable for our data analysis, the base measure will be subtracted from the threat measure.

Tower of London Task. This task assesses the level of cognitive performance and is implemented similar to Banakou et al. [9] in which three differently colored beads on three chopsticks are displayed at descending height. Within three moves, the beads have to manipulate from a predetermined starting position to another set of pins to match the position of the beads in the model. As in Banakou, a point-based algorithm will be used to evaluate the performance (similar to Krikorian et al. [23]).

Questionnaire. We will use the five questions adapted from Banakou et al. [9] to assess self-presence (body ownership) and agency.

3.3 Design Elements

Physical feedback. Physical feedback will be designed by providing feedback in form of vibrations through the IVR gloves. Thus, when individuals in the high physical feedback condition touch objects, the gloves will vibrate. For individuals in the low physical feedback condition, this vibration will be missing.

Avatar design. Avatar design will be operationalized by either using a normal-looking male avatar (normal intelligence condition) or an avatar looking similar to Einstein (high intelligence condition).

3.4 Procedure

Apart from the physical feedback conditions, the threat to the virtual body, and the psychophysiological measurement, the overall procedure is adapted from Banakou et al. [9]. Participants will be told that they will take part in a study investigating the effects of virtual reality on user experience. They will be invited to the laboratory at two time points: during their first visit participants will sign informed consent, complete measures for self-esteem as well as cognitive ability, and complete the premeasure of the tower of London task. One week later, the IVR session takes place. First, participants are lead into a changing room to put on the HRV belt. Next, the experimenter attaches the electrodes for EDA measurement to the inside of the middle and index finger. Afterwards, participants will get instructions on how to put on HTC Vive Trackers and Hi5 VR Gloves. Subsequently, they will put on the HTC Vive HMD and will see a virtual environment which consists of a room with a mirror, a chair, and a virtual body (which either looks like a human or like Einstein, according to the condition) from a first person perspective. When looking in the mirror, participants can see the virtual body mirrored, thus, in a third person perspective. Participants are then asked to get accustomed to the virtual body by moving their body parts and to look around in the virtual room.

To engage participants into being in the virtual environment, and to make the physical feedback conditions salient, participants will be asked to complete a task in which they have to locate numbers in the room and sort them in ascending order using their hands. In the high physical feedback condition, participants will receive physical feedback when touching the numbers, whereas this feedback will be missing for participants in the low physical feedback condition.

In the next part of the experiment, participants will be seated on a chair and asked to answer the virtually presented questionnaire regarding self-presence (body ownership) and telepresence. After they have finished answering the questionnaire, participants will be told that they have the chance to play a game with a box-shaped robot. In this game, participants will be asked to put their right hand on a virtual pad which is tantalized to them by the box-shaped robot. Then, the robot will pull out a knife and starts to stab the knife quickly in the space between the fingers of the participants. This serves as a threat for the virtual body. We chose a game in which the virtual body is not actually hurt because we wanted to refrain from permanently damaging the virtual body, as we expected that this might interfere with the intelligence salience of the Einstein body (participants could remember their experience as threatening rather than as being embodied in the body of an intelligent person). Afterwards, participants will take off the HMD and do the post measure of the tower of London task. Finally, participants will be thanked and debriefed.

4 Discussion

With our results, we aim to gain insights into the working mechanisms through which body ownership illusions affect cognitive performance. First, our research contributes to the literature indicating that self-presence in the form of body ownership illusions can be measured by biophysiological variables [3, 4] by delivering a more practice-oriented view on physical feedback. Second, we aim to contribute to literature indicating that visuotactile feedback can indeed strengthen self-presence [4]. Third, by testing whether strengthening self-presence can increase cognitive performance, we contribute to practice increasing the knowledge on how immersive virtual reality can be designed to shape behavioral and cognitive outcomes in a beneficial way [8, 9, 24].

References

1. Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 6,* 603–616. https://doi.org/10.1162/pres.1997.6.6.603.

2. Schultze, U. (2010). Embodiment and presence in virtual worlds: a review. *Journal of Information Technology., 25,* 434–449. https://doi.org/10.1057/jit.2010.25.
3. Maselli, A., & Slater, M. (2013). The building blocks of the full body ownership illusion. *Front Hum Neurosci., 7,* 83. https://doi.org/10.3389/fnhum.2013.00083.
4. Kokkinara, E., & Slater, M. (2014). Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion. *Perception, 43,* 43–58. https://doi.org/10.1068/p7545.
5. Kilteni, K., Bergstrom, I., & Slater, M. (2013). Drumming in immersive virtual reality: The body shapes the way we play. *IEEE Transactions on Visualization and Computer Graphics, 19,* 597–605.
6. Banakou, D., Hanumanthu, P. D., & Slater, M. (2016). Virtual embodiment of white people in a black virtual body leads to a sustained reduction in their implicit racial bias. *Frontiers in human neuroscience, 10,* 601. https://doi.org/10.3389/fnhum.2016.00601.
7. Hasler, B. S., Spanlang, B., & Slater, M. (2017). Virtual race transformation reverses racial in group bias. *PLoS ONE, 12,* e0174965. https://doi.org/10.1371/journal.pone.0174965.
8. Osimo, S. A., Pizarro, R., Spanlang, B., & Slater, M. (2015). Conversations between self and self as Sigmund Freud-A virtual body ownership paradigm for self counselling. *Sci Rep., 5,* 13899. https://doi.org/10.1038/srep13899.
9. Banakou, D., Kishore, S., & Slater, M. (2018). Virtually being einstein results in an improvement in cognitive task performance and a decrease in age bias. *Frontiers in Psychology, 9,* 917. https://doi.org/10.3389/fpsyg.2018.00917.
10. Sanchez-Vives, M. V., Spanlang, B., Frisoli, A., Bergamasco, M., & Slater, M. (2010). Virtual hand illusion induced by visuomotor correlations. *PLoS ONE, 5,* e10381. https://doi.org/10.1371/journal.pone.0010381.
11. Tieri, G., Tidoni, E., Pavone, E. F., & Aglioti, S. M. (2015). Body visual discontinuity affects feeling of ownership and skin conductance responses. *Scientific Reports, 5,* 17139. https://doi.org/10.1038/srep17139.
12. Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature, 391,* 756. https://doi.org/10.1038/35784.
13. Kilteni, K., Maselli, A., Kording, K. P., & Slater, M. (2015). Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience., 9,* 141. https://doi.org/10.3389/fnhum.2015.00141.
14. Davis, M. H. (1980). *A multidimensional approach to individual differences in empathy*.
15. Regan, D. T., & Totten, J. (1975). Empathy and attribution: Turning observers into actors. *Journal of Personality and Social Psychology, 32,* 850–856.
16. Oh, S. Y., Bailenson, J., Weisz, E., & Zaki, J. (2016). Virtually old: Embodied perspective taking and the reduction of ageism under threat. *Computers in Human Behavior, 60,* 398–410. https://doi.org/10.1016/j.chb.2016.02.007.
17. Maister, L., Slater, M., Sanchez-Vives, M. V., & Tsakiris, M. (2015). Changing bodies changes minds: Owning another body affects social cognition. *Trends in Cognitive Sciences., 19,* 6–12. https://doi.org/10.1016/j.tics.2014.11.001.
18. Petkova, V. I., & Ehrsson, H. H. (2008). If I were you: Perceptual illusion of body swapping. *PLoS ONE., 3*(1–9), e3832. https://doi.org/10.1371/journal.pone.0003832.
19. Petkova, V. I., Khoshnevis, M., & Ehrsson, H. H. (2011). The perspective matters! Multisensory integration in ego-centric reference frames determines full-body ownership. *Frontiers in Psychology, 2,* 1–7. https://doi.org/10.3389/fpsyg.2011.00035.
20. Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First person experience of body transfer in virtual reality. *PLoS ONE, 5,* e10564. https://doi.org/10.1371/journal.pone.0010564.
21. Cacioppo, J. T., Tassinary, L. G., Berntson, G. G.: (2007). *Handbook of psychophysiology*. Cambridge University Press, Cambridge; New York. https://doi.org/10.13140/2.1.2871.1369.
22. Pollatos, O., Herbert, B. M., Matthias, E., & Schandry, R. (2007). Heart rate response after emotional picture presentation is modulated by interoceptive awareness. *International Journal of Psychophysiology, 63,* 117–124. https://doi.org/10.1016/j.ijpsycho.2006.09.003.

23. Krikorian, R., Bartik, J., & Gay, N. (1994). Tower of London procedure: A standard method and developmental data. *Journal of Clinical and Experimental Neuropsychology, 16,* 840–850. https://doi.org/10.1080/01688639408402697.
24. Ott, M., Freina, L. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In: *Conference proceedings of »eLearning and Software for Education*« (pp. 133–141) (eLSE).