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Anthropomorphism and Illusion of Virtual Body Ownership

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Abstract

In this paper we present a novel experiment to explore the impact of avatar realism on the illusion of virtual body ownership (IVBO) in immersive virtual environments, with full-body avatar embodiment and freedom of movement. We evaluated four distinct avatars presenting an increasing level of anthropomorphism in their detailed compositions. Our results revealed that each avatar elicited a relatively high level of illusion. However both machine-like and cartoon-like avatars elicited an equivalent IVBO, slightly superior to the human-ones. A realistic human appearance is therefore not a critical top-down factor of IVBO, and could lead to an Uncanny Valley effect.

Categories and Subject Descriptors (according to ACM CCS): Three-Dimensional Graphics and Realism [I.3.7]: Virtual reality—

1. Introduction

The Illusion of *Virtual* Body Ownership (IVBO) lets users accept virtual body parts to be their own. It extends the Rubber Hand Illusion (RHI) of Botvinick and Cohen [BC98] to Virtual and Augmented Reality (VR and AR), where virtual limbs or complete avatars are used as digital representations of the users' bodies to provide a sense of embodiment inside of the virtual worlds. The RHI motivated multiple experiments which transferred the general idea of artificial limbs and bodies to the virtual domain. Replications in AR first confirmed the effect of body ownership to also exist for virtual replicas [IdH06], even though it was weaker as in the original condition with a real rubber hand. The authors explained this with the missing 3D-ness since the virtual arm was merely projected on the table in front of the participants.

Follow-up work extended this work to full immersive VR setups where the complete body was represented, instead of only selected body parts [SSSV*10]. Numerous studies demonstrated then that a first-person perspective of an avatar in an immersive VR setting can trigger strong IVBO effects. This is true even though the virtual body may differ considerably from the real person's body. Surprisingly, one's bodily self-perception can be temporarily shifted towards the virtual body of an avatar with a different gender [SSSV*10], age [BGS13], race [PSAS13], body shape [NGS*11], longer limbs [KGS12], and even with a different posture [dlPWL*10].

Previous research suggests that such an illusion is the result of an interaction of both bottom-up (synchronous visual, motor, and tactile sensory inputs) and top-down (preexisting visual and proprioceptive body representations) factors [TH05]. Bottom-up factors alone have been enough to evoke the illusion in past studies [SVSF*10]. Kokkinara & Slater could also show that the visuomotor synchrony seems to contribute more to a strong IVBO compared to visuotactile synchrony, although a disruption of either of them can equally lead to a break in the illusion [KS14].

However, the majority of these previous studies presented avatars having (1) a strong resemblance to humans, usually with (2) a limited freedom of movement (i.e., participant were required to reproduce a particular movement pattern or simply being immobile), and/or often only (3) partial body tracking. In fact, the influence of one important top-down factor, the virtual body realism in terms of visual human resemblance (or anthropomorphism) has barely been researched, especially with natural whole-body interactions.

The work reported here investigates to what degree visual anthropomorphism (visually perceived human resemblance or characteristics) of a virtual body representation is necessary to induce, strengthen or weaken the IVBO. It is based on a full immersive setup using a head-mounted display, an extended freedom of movement, as well as a full-scale body tracking (using inverse kinematics) to reduce potential unwanted side-effects from technical limitations.

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2. Anthropomorphism Model for IVBO

Anthropomorphism is understood as the attribution of humanlike properties or characteristics to real or imagined non-human agents and objects [EWC07]. In this work, these characteristics are separated into two disjunct categories:

1. **Anatomy:** The general structural information of the number and type of body parts and their interconnection.
2. **Composition:** The specific body parts' shape, scale, dimension, surface topology, texture, and color.

This study investigates the influence of the degree of human resemblance on the IVBO as perceived from visual cues of compositional changes. Figure 1 illustrates the type of avatars used in this study:

1. *R*-avatar: A humanoid machine (a robot).
2. *B*-avatar: An abstracted human form (a block-man).
3. *H*-avatars: (Photo-)realistic humans (a contemporary human male and female)

The robot and block-man are both clearly not human. They keep a general humanoid anatomy but modify composition into two distinct directions. The block-man is an iconic abstraction of a human prototype. It is a *stylized* human, sometimes referred as a *cartoon*, which is the result of an "amplification through simplification" of a human body [McC93]. To a certain extent, it is a sort of universal human avatar (genderless, race-less, ethnicity-less). The robot, on the other hand, is a compositional specialization very distinct from a concrete typical human composition. In theory, this composition with its strong mechanical aspect gives it less human characteristics than the block-man. The *H*-avatars represent the higher level of human-likeness, they are close but not perfect imitations of real humans.

3. Experiment

Participants were immersed in a game-like scenario, where they were provided with a virtual body, seen in a first-person

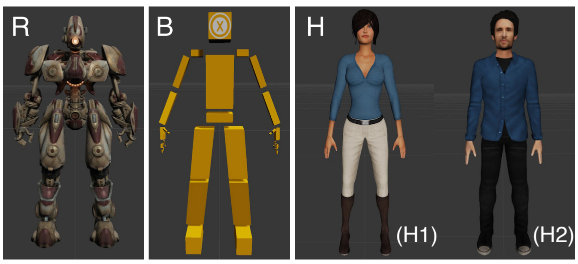

Figure 1: ***Avatars.*** *Each participant experienced only one virtual avatar among the four available: a Block-man (B), a Robot (R), or one of the two Human avatars (H), which depending on their gender was either a female avatar (H1) or male avatar (H2)*

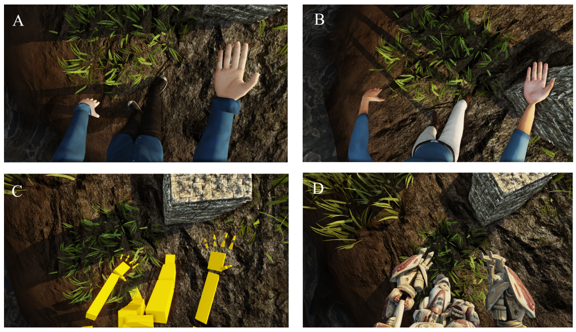

Figure 2: ***Avatars from first-person perspective.*** *Participants saw the virtual avatars from a first person perspective and synchronized with their real body movement in space and time. Each participant experienced either a realistic human body (male (A) or female (B)), or an unrealistic one such as a body made of simple blocks (C), or one made of metal like a robot (D).*

perspective via a head-mounted display (HMD). The participant's body motion and movement were mapped in real-time to their virtual body, which was co-located and aligned with their real body. The task consisted of a simple game of finding and touching targets (here represented by large spheres) randomly appearing at different places in an exotic forest-like environment (Figure 3). The overall game area spanned a volume of 18 m^3 (3 length *x* 3 width *x* 2 height meters). During one game round, participants had 2.5 minutes to touch a maximum number of spheres using their virtual hands or feet.

We adopted a 3X2X2 mixed design with the between-subjects factor being the level of anthropomorphism of the virtual body and the within-factors being the level of virtual threat participants experienced:

- **The between-subjects factor** was composed of three conditions represented by four distinct avatars with varying levels of anthropomorphism based on their detailed composition. Each participant experienced either the R-avatar, the B-avatar, or one of the H-avatars (H1, H2) depending on the participant's gender. Figure 2 illustrates the different conditions as seen from the user's point of view.
- **The first within-factor** had two conditions: the presence of a permanent threat (*F*-condition) or its absence (*NF*-condition). This permanent threat was represented by fire torches (Figure 3).
- **The second within-factor** was the presence or absence of a sudden threat (*E*-condition and *NE*-condition). This threat was represented by a sudden final explosion and wild fire happening at the end of the experiment, during the second trial (Figure 3).

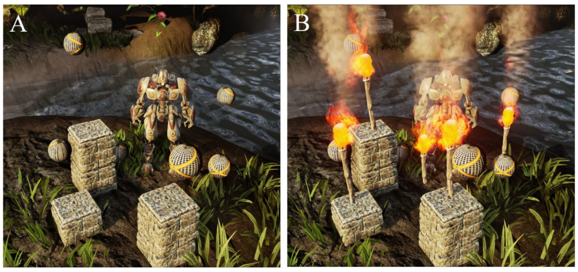

Figure 3: ***Task-area with Explosion Condition.*** *Picture (A) shows the sudden explosion nearby the game area happening at the end of the experiment (in the* E*-condition). The explosion is followed by a rapid wildfire propagation, which is surrounding the user within few seconds. This is depicted in picture (B).*

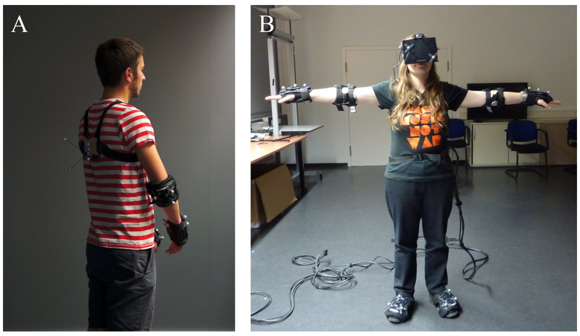

Figure 4: ***Apparatus with Tracking.*** *Participants wore markers on the elbows, the hands, the torso and the feet (A). To track the head movements, markers were placed on the head-mounted display. The necessary cables for the head-mounted display were carried in a small bag on the back of the participants (B).*

3.1. Measurements

The following measures were collected in this study:

1. **IVBO**: A post-experimental questionnaire was designed to subjectively measure the IVBO based on [SSS13, SSSV*10, KGS12, NGS*11]. It is composed of 12 closed questions and 3 open questions (see table 1)
2. **Simulation Sickness**: The results of the simulator sickness questionnaire (SSQ) [KLBL93] were solely used to sort out participants.
3. **Galvanic Skin Response (GSR)**: The participant's level of stress was evaluated using skin conductance measurements. An higher IVBO should be reflected by an higher level of stress when facing the threats [SKMY09].
4. **Task Performance**: The performance was measured through the number of spheres touched in 2.5 minutes.

3.2. Rational

The experiment was designed in order to entice participant to keep a constant visual contact with all their virtual body parts, while moving and interacting naturally. The physical task involved whole-body interactions and walking movements inside of the interaction space of the virtual environment. The use of a simple task with large targets (≈ 30 cm diameter) and substantial target distances was also chosen to foster substantial movement for all participants. Our objective was to stimulate a perceptual process rather than cognitive load (e.g., by reasoning and problem solving) for all participants. Hence, simple and natural interaction and navigation mechanisms were chosen to let participants focus on their virtual body rather than on solving the task. A short gameplay duration was chosen to avoid the development of an excessive feeling of boredom, physical fatigue, or simulation sickness (aka cyber sickness).

Exposing the participants' virtual body to some kind of threat - in this case fire - and measuring the participants' reaction to it is a common means to measure the strength of the illusion [SSSV*10, SSS13, PE08, Ehr, AR03]. The idea behind it is that if an external object became integrated into the user's mental body image, a physical threat to this object should trigger a similar stress response as the normal anticipation of bodily harm to one's real self [AR03]. Consequently, the stronger the IVBO, the more participants should be worried about their virtual body being hurt.

3.3. Apparatus

As depicted by figure 4, participants were visually immersed in a virtual environment using the Oculus Rift stereoscopic HMD, with a field of view of 90° horizontally and a resolution of 640x800 pixel per eye. Participants' movements across the room were captured using a marker-based infrared optical tracking system. Rigid-body targets (i.e., pre-defined geometric configurations of retro-reflective markers [PK08])

Table 1: ***Illusion of Virtual Body Ownership (IVBO) Questionnaire.*** *(with other factors related to the virtual body and experimental task). Responses were given on a 7-point Likert-Scale where 1 meant "not at all" and 7 "very" (with the exception of item myExpJoy which rates from "not at all" to "very much" and the open questions). Certain questions were added to measure additional factors such as the enjoyment of seeing and controlling the virtual avatar (myExpJoy-item). The humanBody-item was introduced to validate that participants differentiated between the levels of human resemblance of the avatars as well. The bodyChange-item and weightBody-item test whether the compositional differences between the avatars had an influence on the participants self-perception since the block avatar and the robot could possibly be perceived lighter or heavier due to their texture and structure. Additional open questions addressed when exactly the illusion of owning the virtual body was especially strong or weak, which factors contributed to that feeling and why or why not participants reacted to the fire.*

Topic	item	Question
Body Ownership	*myBody*	I felt like the body I saw in the virtual world was my body.
	twoBodies	I felt as if I had two bodies.
	bodyIntensity	The illusion of owning a different body than my real one was very strong during the experience.
Agency	*myMove*	The movements I saw in the virtual world seemed to be my own movements.
	myMoveJoy	I enjoyed controlling the virtual body I saw in the virtual world.
Threat	*avoidBody*	I tried to avoid touching the flames.
	harmBody	In between I was worried that I might get harmed if I touched the flames.
Real Body Change	*bodyChange*	At a time during the experiment I felt as if my real body changed in its shape and/or texture.
	checkBody	After taking off the HMD, I felt the need to check that my body does really still look like to what I had in mind.
	weightBody	I felt an after-effect as if my body had become lighter/heavier.
Enjoyment	*myExpJoy*	How did you like the overall experience in the virtual world?
Anthropo -morphism	*humanBody*	I felt like the virtual body I saw looked human.
Open Questions	*factors*	What exactly gave you the feeling that the virtual body is your own, or what has prevented it?
	factors	When did the feeling of owning the virtual body was especially strong or weak?
	factors	Why have you responded to the fire or why not?
	misc	Any other comments?

were placed on participants' head, elbows, hands, torso and feet to capture 6 degrees of freedom (DOF) for the respective body parts. The movements were captured with six Vicon Bonita-10 optical cameras running at 120 frames per second. Participants were also wearing wireless stereo head-phones.

To measure the skin conductance of the participants, a sensor from eSense was used. Two electrodes were attached to the fingers of the participant's non-dominant hand. The skin conductance was measured in microsiemens (μS) and five values per second were recorded. The measurements were collected during the VR training phase to act as a baseline, as well as in both game sessions.

The virtual environment was implemented using the Unreal Development Kit (UDK). On top of this game engine, an extra module was developed (named *UnrealMe*) to animate the virtual body skeleton according to the captured motion data received via VRPN (Virtual-Reality Peripheral Network) [THS*01]. As previously mentioned, only the participants' feet, hands, elbows, head and torso were tracked. Therefore, inverse kinematics was used to ensure that the other parts of the virtual body which were not tracked, such as their knees or hips, would move correspondingly.

To guarantee that our system provides synchronous temporal visuomotor stimulation, we performed video-based measurements of the end-to-end latency using a frame-counting method as described in [HFP*00]. This method is less accurate than the pendulum method discussed in [Ste08], but better adapted to immersive game measurements [LCC*12]. The average end-to-end latency between movements of the participant and the perception of virtual body movement was evaluated to approximately 88 milliseconds ($\pm$ SD 7), which is below the threshold required for real-time interactions ($\leq$ 150 ms [LCC*12]). Measurements were realised with videos recorded at 480 Hz with the Casio EX-ZR200 Camera at a resolution of 224 *x* 160. The overall system delivered an average frame rate of $\approx$ 55 frames per second (50-62) for an average number of 600K triangles per frame.

Additionally, a calibration procedure was carried out for each participant to ensure spatial visuomotor stimulation between the virtual and the real body. The scale of the virtual body was adapted to the user's body in order to be correctly co-located, aligned and proportional to each other. This procedure was realised using the tracking system configuration software. Manual adjustments were then performed at the simulation engine level via customised commands. The rigid-target center offsets were also adjusted via the tracking system software to match real hands, head, torso, feet and eyes. This avatar calibration procedure was completed when the user confirmed the perception of a strong local and global spatial synchrony. At the local level, we asked users if they could see their virtual hands touching when touching their real hands in front of them. At the global level, they had to confirm that their virtual feet touched the virtual floor when their real ones touched the real floor.

3.4. Procedure

The overall experiment followed ten main stages:

1. *Pre-Questionnaires*: Completion of a consent form, a demographic questionnaire, and an initial SSQ by the participants.
2. *Equipment*: Gear-up participants with the equipment for the physiological measurements (skin conductance sensors) and motion tracking (rigid-body targets).
3. *Avatar Calibration*: Calibrate the tracking system and avatar's dimension to match participants' height and proportions. Introduce participants to their avatar. Let them see their avatar in third person perspective mirroring their movement and motion on a large screen ($3X2$ meters). This procedure takes place in a neutral virtual environment replicating the VR lab room in which the study takes place.
4. *VR Acclimatization*: Equip participants with the HMD and immerse them in the virtual training room. Calibrate the HMD for comfort and correct stereoscopy. Carry out avatar calibration until participants agree that their virtual body dimension and alignment seems natural. Ask them to walk around in the virtual room to get familiar with wearing the HMD and navigate in the virtual environment. Instruct them to check their virtual body again and to report if some movements still feet unnatural or wrong.
5. *Task Practice (navigation and interaction)*: Let participants practice the game task. Explain to them that they have to look for a sphere somewhere in the environment, touch it - either with their hands or their feet - and once they touch it it will disappear and cause a new sphere to appear somewhere else.
   The training round is ended after participants touch three virtual spheres. Stop skin conductance baseline measurement. Ask participants to take off the HMD. The whole training and calibration procedure took between 10 and 15 minutes per participant.
6. *Break and Questionnaires*: Ask participants to fill out the SSQ before the actual experiment. Let them have a break as long as they feel it to be necessary and offer refreshments. Explain the task again once the participant are ready. Immerse them in the virtual environment in either the *F*- or *NF*-condition, depending on the counterbalancing. Start skin conductance measurement again.
7. *Experimental Condition One*: Virtual shining squares on the ground mark the starting point. As soon as participants step on them they hear a signal and the first sphere spawns somewhere in the interaction area. Participants have 2.5 minutes to touch these spheres in each condition. A sound indicates the end of the game to the participant.
8. *Break and Questionnaires*: Take off headphones and the HMD. Stop skin conductance measurement. Let participants fill-out the SSQ. Let them have a break as long as they feel it to be necessary.
9. *Experimental Condition Two - With Explosion*: Second experimental round takes place with the same procedure as the first round with only a change in the *F*- or *NF*-condition. At the end of the game time, a violent explosion happens nearby the interaction area. A fire from the explosion quickly propagates and completely surrounds the virtual avatar within a few seconds (Figure 3). The display slowly fades out. Once it is completely black, the participants are told that the experiment had ended
10. *Post-Questionnaires*: Stop skin conductance measurement after the last experimental round. Un-equip participants. Ask them to fill out the SSQ as well as the IVBO questionnaire.

The whole experiment took approximately 40 to 60 minutes depending on the break time each participant need.

3.5. Participants

A total of 35 participants with normal to corrected-to-normal vision were recruited for the experiment. All of them were students or staff of the university. Two participants were sorted out due to high simulator sickness values. The difference between their total simulator sickness scores (*DTS*) right before and after the experiment was more than 1.5 interquartile ranges higher than the third quartile of all differences of all participants which is commonly considered as an outlier ($DTS_1 = 74.80$, $DTS_2 = 127.16$,) [Tuk77]. Three more participants had to be excluded due to technical problems or a misunderstanding of the experimental procedure. Thus, the effective end sample size was n = 30. The average age of participants was $M = 21.60$, $SD = 2.43$. In the human- and robot-condition 3 of the 10 participants were female. In the block-condition 2 of the 10 participants were female. All participants were light-skinned.

4. Results

We analysed the results with one-way and two-way mixed ANOVAs and pairwise comparisons post hoc tests at the 5% significance level. This study has an explorative aspect which is to identify potential top-down factors that will influence the IVBO. Thus a strong conservative adjustment of the *p*-level like the Bonferroni correction would raise the possibility of *Type II* errors and thus of rejecting correlations as

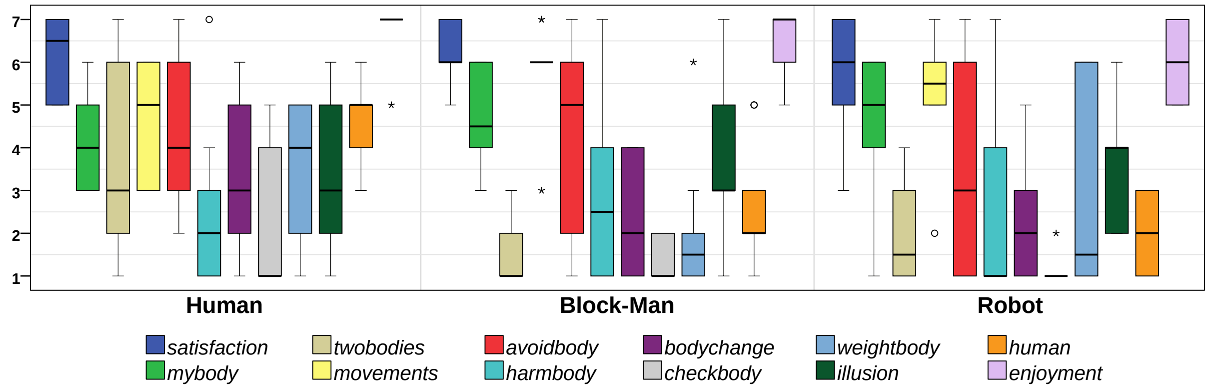

Figure 5: ***Box-plots of the IVBO results.*** *Box-plots showing medians, interquartile ranges, full ranges and outliers.*

non-significant even though they are significant in the real population [Nak04]. To avoid to miss potentially important factors because of such an adjustment it was decided to keep the common p-level of 0.05.

4.1. Human Resemblance

There was a statistically significant difference in the *human-body*-scores between the different avatars, $F(2,27) = 17.16$, $p < .001$. Post-hoc Tukey-HSD-tests were carried out to determine between which conditions there was a difference. They showed that the *humanbody*-scores for the H-avatar ($M = 4.70$, $SD = .949$) were significantly greater than for the B-avatar ($M = 2.60$, $SD = 1.430$, $p < .001$) and for the R-avatar ($M = 1.90$, $SD = .876$, $p < .001$). The H-avatar has been thus qualified as the closest to a real human, followed by the B-avatar and finally the R-avatar. The reported levels of visual anthropomorphism were of ≈67% for the H-avatars, ≈37% for the B-avatar, and finally ≈27% for the R-avatar.

4.2. Illusion of Virtual Body Ownership

Figure 5 summarizes the IVBO questionnaire scores obtained for each avatar. There first were no significant differences found between avatars for the individual items. In order to further confirm this result, we performed a statistical test of equivalence on the three questionnaire-items directly related to the illusion: *mybody*, *twobodies* and *bodyintensity*-items. We applied the TOST-method ('*two-one-sided-test*') which is a common way to test the equivalence of two or more samples [RL11]. Based on [dD10] it was decided to treat the results from the Likert-scales of the deployed questionnaires as interval-scaled and assume their normal distribution as suggested by [GR04]. The main results presented in table 2 reveal a strong equivalence for the three virtual body ownership questions (i.e. *myBody*-, *bodyIntensity*- and *twoBodies*-items). However, the *twoBodies*-item is only equivalent for the non-human avatars, with a value significantly lower for the human avatars.

4.3. Task Performance

A two-way mixed ANOVA showed a significant main effect of the within-variable condition ($F(1,27) = 44.544$, $p < .001$) but not of the between-variable avatar ($F(2,27) = .280$, $p = .758$) nor of the interaction between avatars and the condition ($F(2,27) = .474$, $p = .628$). This means that in the NF-condition significantly more spheres were touched than in the F-condition, independently of the avatar's type.

4.4. Galvanic Skin Conductance

A two-way mixed ANOVA showed that there was a significant main effect of the explosion (dynamic sudden threat) on the measured skin conductance values for each participant when compared to the baseline training group ($F(1,26) = 24.138$, $p < .001$). The explosion appears to have created strong emotional response. In the meantime, there was no main effect of the avatar condition ($F(2,26) = .416$, $p = .664$) or of the interaction effect between the explosion and the avatar ($F(2,26) = 1.297$, $p = .091$). Consequently, none of the avatars seemed to have triggered a higher or lower emotional response to the sudden threat. We also observed that there were no significant differences between the NF-condition and F-condition across avatar and users.

4.5. Discussion

We observed that no significant difference in terms of task performance or skin conductance (stress) was found. This corroborates the equivalence of IVBO in between avatars as previously suggested by the analysis of the questionnaire. The avatars seem to have elicited a very similar response, despite their non-human or human appearance. However, the participants with the human-avatar had a significantly

Table 2: ***Results of the Confidence Interval Equivalence Testing.*** *Table showing the standard errors of the differences of the means (SE_d) of the three relevant IVBO-questions and the lower (CI_l) and upper (CI_u) bounds of the 90%-confidence intervals for the difference of means for each possible pairing of avatars. CI-values that exceed a value of ±1 are marked with a ∗ (i.e., the maximum difference between means which will be considered as equivalent).*

	myBody			***twoBodies***			***bodyIntensity***		
	SE_d	CI_l	CI_u	SE_d	CI_l	CI_u	SE_d	CI_l	CI_u
Humans - Robot	.204	-.754	-.046	.252	**1.26***	**2.13***	.230	-.899	-.101
Humans - Block Man	.158	-.974	-.426	.242	**1.58***	**2.42***	.253	-.939	-.090
Robot - Block Man	.206	-.657	.057	.139	.059	.541	.236	-.910	-.090

stronger feeling of having *two bodies*. A strong IVBO would normally mean a weak feeling of having two bodies and vice versa.

A correlation between an increased human resemblance and a stronger feeling of having two bodies seems contradictory at first. But a similar effect is well known for human resemblance of virtual agents and robots [MBB12, Gel08, NR05]. The *Uncanny Valley* hypothesis suggests that more human characteristics equal more acceptance up to a certain point after which there occurs a sudden dip in response due to subtle imperfections of appearance and/or movement [Mor70]. Hence, a potential explanation of the higher scores on the *twoBodies*-item is an *Uncanny Valley*-like effect to also appear for human avatars seen from first person perspective in addition to the confirmed effect for the third person perspective of agents and robots. The answers to the open questions appears to reveal such an acceptance drop for human-like avatars. Participants in the *H*-condition seemed to look a lot more at details of the virtual body such as exact proportions or clothing (*"I felt like the length of my arms was not represented correctly"*). Several participants in the *H*-condition (5 out of 10) pointed out that the avatar had a different hair colour, clothing, was thinner than they actually were or seemed to have longer arms which diminished the illusion for them (*"The body did not bear any resemblance to me (physique, hair colour etc.)"*). For the other two avatars such detailed differences were not reported.

5. Conclusion

As illustrated by Figure 6, we observed that all avatars elicited a high IVBO with a slight decrease of acceptance towards an avatar with a higher human resemblance indicating a potential existence of an *Uncanny Valley* effect with first-person avatars. The elicitation of a sense of embodiment with clearly non-human avatars has both fundamental and practical interests. First, it appears possible to convincingly experience alternative body forms in future generations of interactive applications and games. But, more importantly, it also opens novel perspectives to further study the perceptual, psychological and cognitive processes underlying our own sense of body ownership.

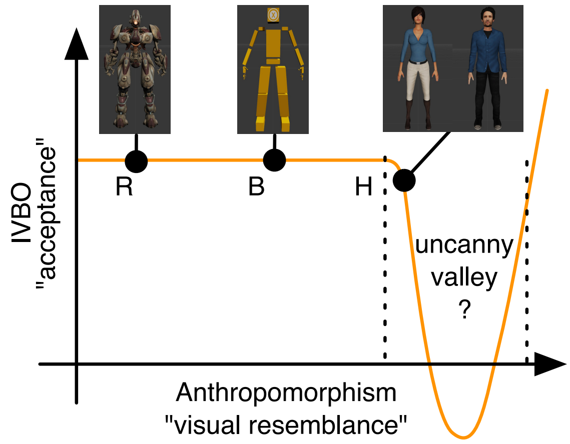

Figure 6: ***Results****. Approximate relation between IVBO strength and the degree of anthropomorphism of the avatars with a potential existence of an Uncanny Valley effect.*

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