Any "Body" There?
Avatar Visibility Effects in a Virtual Reality Game

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Figure 1: Experimental Conditions - different avatar representations as seen from the player's viewpoint (first-person perspective). None: an invisible body (only models of the 3D controllers and a shield attached to the player's torso). Low: a visible body but with only hands and forearms. Medium: a visible body with head, neck, trunk, forearms, hands, and tail for the lower body parts.

ABSTRACT

This article presents an experiment exploring the possible impact of avatar's body part visibility on players' experience and performance using current Virtual Reality (VR) gaming platform capacities. In an action-based VR game, a player sees an avatar in first person perspective which is replicating his/her hand, head and body motion. In contrast to the expected outcome from non-game VR contexts, our results did not reveal significant differences with an avatar presenting an increasing number of visible body parts. The body ownership, immersion, emotional and cognitive involvements as well as the perceived control and difficulty were not improved with a more coherent virtual body. This tends to confirm the strong performance aspect of action-based games, whereby control efficiency and enemy awareness is paramount, and could overcome the perceptual, behavioural or emotional effects of avatar embodiment. Digital games are indeed prone to create an intense flow state typically reducing self-awareness, and focusing on the game completion and high performance achievements. However, further experiments with full-body tracking and different game types are necessary to confirm this trend. This research outcome motivates further analysis of the mutual influence of bottom-up and top-down factors of avatar embodiment causing psychophysical effects. In addition, it provides useful indications for VR game developers and researchers on possible effects and evaluation methods.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

1 INTRODUCTION

The term "avatar embodiment" describes the *physical process that employs the Virtual Reality (VR) hardware and software to substitute (parts of) a person's body with a virtual one* [43]. Such a VR system captures the motion of a user's body and uses it to animate a virtual character representing the self. This avatar is viewed in first or third person perspective via a Head-Mounted Display (HMD) providing synchronized visuomotor feedback to the user. A virtual mirror is often placed in the virtual environment for the user to view the reflection of their avatar's body moving as they move. Sometimes, avatar embodiment is performed by tracking a limited number of limbs (e.g. only hands, foot and/or torso tracking), in conjunction with inverse kinematics solutions [36], or even eye [5] or finger tracking [1]. In avatar embodiment studies, three types of bodies are distinguished: i) The *Physical Body*: the participant's own body, ii) The *Experienced Body*: the body the participant feels s/he has at that moment and iii) the *Virtual Body* (hence VB): the body the participant sees when s/he looks down in the virtual environment at the place where s/he expects her/his physical body to be [32].

Numerous research confirmed that avatar embodiment is not only extending the feeling of *being inside* a different world [42], but can also elicit the particular feeling of *being somebody else* [18]. The illusion of virtual body ownership (IVBO) describes when a person perceives the body of his/her avatar to be his/her own body [23]. Avatar embodiment also produces a more immersive VR simulation as well as more genuine reactions to virtual events [43]. Such effects seem desirable and attractive for entertainment applications such as VR games to increase the overall gaming experience and to contribute to the success of VR gaming products.

However, the majority of avatar embodiment studies rely on fully-body motion capture devices with specific experimental conditions and constraints which are not directly applicable to current VR games. The majority of VR games only provides a partial digital representation of the users' avatars due to unavailable consumer-grade full-body motion capture devices and technological constraints. Thus, players are often just represented by floating virtual hands replicating their hand movements in the virtual world. In 2016, only 9% of VR games proposed a partial body representation, using floating virtual hands, while only 4.5% completed them with a floating torso and/or head [27]. In this paper, we investigate the effect of varying the number of visible body parts of an avatar on player experience and performance. Our contributions are three-fold and provide: i) a review of possible effects of avatar embodiment on VR games, ii) an empirical study comparing three levels of avatar body visual completeness, and iii) a discussion of limitations and possible solutions to consider in future studies

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2 RELATED WORK

In 2000, Slater and Steed [42] confirmed that participants who had to interact with virtual objects through a *VB* had a higher sense of presence than those who interacted with a traditional user interface (pressing a button). Since then, numerous studies demonstrated interesting perceptual, behavioral and psychological effects caused by embodiment which could possibly also influence an embodied players' experience and performance. The following sections summarize the causes and main effects.

2.1 Potential IVBO Causes

Previous research suggests that the IVBO is the result of an interaction of both bottom-up factors (synchronous visual, motor and tactile sensory inputs) and top-down factors (similarity of form and appearance) factors [48]. It is a combination of multisensory integration and a conceptual interpretation of the observed virtual body parts. The illusion of body ownership is driven by an interplay between top-down and bottom-up factors and certain requirements have to be met to be able to induce the illusion at all. Bottom-up factors such as (1) first-person perspective, (2) synchronous visuotactile stimulations, and (3) synchronous visuomotor stimulations are very strong triggers for the IVBO effect [43]. These factors alone have been enough to evoke the illusion in past studies [39]. 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 [20]. Debarba et al. [9] did not perceive differences between 1PP (first-person perspective) and 3PP (Third person perspective) suggesting that visuomotor synchrony dominates over perspective.

2.2 Being Someone Else

An interesting aspect especially for games is the evocation of a sense of ownership from avatars which are quite different from the user's real body. This illusion has been elicited with avatars of a different gender [41], age [3], race [30], body shape (larger belly shape [28], longer limbs [18]), larger/smaller body size [50]), a different posture [8] and even with non-Human-looking avatars (i.e., robot, block-man and mannequin) [23].

2.3 Acting Like Someone Else

A *VB* which is not resembling the appearance of one's real body does not only elicit the impression to be somebody else. It effectively modulates and changes thinking, feeling and acting to mimic the virtual other as anticipated and imagined by the user. The visual representation of the body subconsciously and quickly changes people's body schema and the resulting state of mind. Altering the sense of one's body is a powerful illusion as it appears to strongly influence one's behaviour [17], attitude [3, 30], emotional involvement [8] and physical discomfort [8]. The changes caused by the avatar's visual and behavioral characteristics are often referred to the *Proteus effect* [52]. To a certain extent, there is a transfer of attributes from the avatar to the user. Participants unconsciously inferred and projected the avatar's characteristics on themselves, and temporarily modulated their self-perception to reflect them (e.g. feel smaller or younger [41]). This could be better understood as a double-mirroring metaphor: *the avatar mirrors your movement, you unconsciously mirror the avatar's attributes*. For instance, if the avatar is a child, you will feel like a child [3]. Notably, these changes can also continue to have an effect after the evoking stimuli have vanished. This creates a causal connection between changes in the virtual to the real world, where users still feel thinner or bigger after the VR experience. Not only the behavior is affected by the avatar's appearance, but also the whole perception of the virtual environment. You and Sundar [53] demonstrated that players with customized avatars perceived a virtual hill as being more difficult to climb when their avatar was equipped with a heavy backpack.

2.4 Increased Emotional Involvement

Caillois [6] proposes a division of games into four main categories: *Agon* (competition), *Alea* (chance), *Ilinx* (the pursuit of vertigo) and *mimicry*, which involves games of simulation, where a person temporarily sheds his/her personality in order to feign another, like pretending to be a super-hero. Being able to play a role and becoming a game character is an important aspect of many video games. Many players invest extensive hours customizing their virtual representations in massively multiplayer online role-playing games (MMORPGs) [22]. Trepte at al. [47] showed that customizing an avatar increases identification and leads to higher enjoyment. Identification is the degree to which individuals like a character, empathize with a character, or perceive a character as being similar to themselves [51]. Van Looy et al [51] also showed that avatar identification positively predicts empathy, the *Proteus effect*, and the motivations for role-play, customization, and escapism. Birk et al, [4] reported that identification with an avatar in a game will increase the intrinsic motivation of the player. They showed that *similarity* ("*My character is like me in many ways*""), *embodied* ("I feel like I am inside my character when playing"), and *wishful* identification ("I would like to be more like my character") increases autonomy, immersion, invested effort, enjoyment, and positive affect as well as the overall playing time. It is then not unreasonable to assume that avatar embodiment in VR would translate, and maybe amplify, the emotional involvement that stems from avatar identification in traditional gaming platforms (computer, console). A *VB* could provide more intense *mimicry* experience, compared to normal video games, especially because players are actually "dressed-up" as their avatars in VR, virtually wearing the avatar's skin, clothes, and equipment. This could produce a stronger bond between players and their avatars.

2.5 Better Performances

A virtual body could influence the player's performance. First, a *VB* tends to increase spatial understanding. Studies confirmed that a *VB* enhances spatial perception (improved distance estimation [35] and spatial knowledge acquisition and usage [10, 21, 49]. This could increase the player's movement accuracy, or increase the ability to control or dodge projectiles. A virtual body can also supply people with both, a recognizable size reference and an enhanced connectedness to the virtual environment [13, 35], even though VR-typical distance compression might still apply [34].

Second, a *VB* could elicit a higher sense of danger: exposing the participants' virtual body to some kind of threat (e.g. a falling object [54], fire [23], or sharp devices [19] like knifes [11]) and measuring the participants' reaction to it is a common means to measure the strength of the illusion [2, 31, 41, 45]. Here, the rationale is, that if a *VB* becomes integrated into the user's mental body image, a physical threat to the *VB* should trigger a similar stress response as the normal anticipation of bodily harm to one's real self [2]. Consequently, with a *VB* , the players should genuinely be scared when their virtual body is threatened. This higher sensitivity to virtual threats could maybe lead to faster reaction times, or more frequent movements, driven by the genuine motivation to avoid being injured by virtual threats such as projectiles. The effects could be visible by a higher physical involvement and/or higher scores.

Third, a *VB* might induce the perception of a higher emotional and/or physical capacity as caused by the *Proteus* effect. For example, players could gain the sense of being stronger, maybe fearless, and would then be motivated to engage in more intense physical activity. A recent study indicated that a Robot-like avatar tends to produce a certain feeling of security when facing a dangerous situation [24].

2.6 Possible Negative Effects

Avatar embodiment can also produce negative effects. For instance, realistic avatars can negatively impact the perception and acceptance of virtual humans [25, 29]. Recent studies even suggested that more realistic humans could trigger avatar rejection [23]. This effect is often referred to as the *Uncanny Valley* (UV) effect [26] whereby realistic virtual humans appear unintentionally creepy. This avatar rejection should be considered by VR game designers and developers when designing avatars for their players. Previous work [40] revealed that realistic human hands with missing fingers have negative effects such as i) Visually induced phantom pain (fear of amputation and limb loss) lead to strong emotional and behavioral reactions, ii) Uncanny Valley iii) Visually induced identity dysphoria (discomfort through lacking coherence between the physical and virtual body appearance) and iv) A mismatch of visual and haptic cues (feeling of losing body control). Similarly, Argelaguet et al. [1] reported that a more abstract hand elicited a strong sense of control (agency) compared to a realistic human one. However, more realistic hands increased the sense ownership. There is little known about the effect of other missing body parts of an avatar.

2.7 Discussion

Several positive effects from prior research results motivate the use of avatars and an increased embodiment in VR computer games. First, playing the role of someone else is fundamental to many games. Second, the identification with different roles seems to easily be enhanced using full body embodiment approaches as motivated by VR research. Third, increased emotional involvement can increase the overall gaming experience and fourth and last, there also is a potential performance increase for players. Additionally, visuomotor synchrony as the main cause to evoke IVBO has been confirmed. Hence, it apparently is just a matter of further enhancing (consumer) tracking devices in terms of full body coverage and decreased latency to pave the way for embodied VR games. The uncanny valley risk could be avoided just by clever design choices. However, the influence of one important factor, the virtual body coherence, in terms of visual completeness, has never been fully researched. It is particularly interesting to investigate the *VB* visibility factor in a VR game context, where the *VB agency* (the ability to control what happens in the game and experience the results of the choice made) could be more important than *VB* ownership. As players may experience a sense of ownership and/or agency even in the absence of visible avatar body parts, if being (1) sensorially immersed and (2) able to use well-calibrated motion control [27].

3 Experiment

As illustrated by Fig. 2, we adopted a between-subject design with the avatar's number of visible body part as independent variable, itself divided into three main levels: *None*: no avatar body parts (invisible), *Low*: Only hands and forearms visible or *Medium* with head, neck, trunk, forearms and hands connected with particle systems, as well as a tail for the lower body parts (about 50% similarity to Human body). To simulate the first condition *No Visible Body*, the 3D controllers held by the player has virtual proxies (i.e. two exact 3D meshes replicating their shape and color on a one-to-one scale). The player can still interact with the game elements while being aware that his/her virtual body is invisible. This represents the typical virtual hand technique variations used in most VR Games [27]. The two other conditions *Low* and *Medium* represent a clear increase of *VB* visibility, from just seeing humanoid hands and forearms to a *VB* composed of six main body parts: hand, forearm, arm, head, torso, shoulder and a tail. We used an avatar *VB* with a tail instead of humanlike legs and foot because typical VR gaming platforms (e.g. HTC Vive or Oculus) only support head and hand tracking. Our solution for a Medium *VB* is a combination of fixed avatar body parts and Low body tracking. Similar to Roth et al [36], the setup relied on tracking just the head and both hands to replicate the participant's body motion to their *VB* in real-time. We interpolated torso position and direction from the head and hand positions, and replaced the body parts that were not tracked (i.e., legs) with a tail, floating above the floor. As visible in Fig. 2, two particle systems connect the forearms to the shoulders in the *Medium* condition. Their main role is to provide more visible body parts *VB* with a visual continuity between the hands and the rest of the body.

Overall, we hypothesize that: The less virtual body parts are visible, the less intense the player's experience and performance Table 1. We analyzed the experience and performance through a combination of subjective questionnaires and objective metrics (see Table 2 for the complete list of measures taken).

Table 1: Hypotheses.

Hypotheses	Predicted Visibility Effect
H_1 Virtual Body Ownership	*Medium* > *Low* > *None*
H_2 Game Experience	*Medium* > *Low* > *None*
H_3 Game Performance	*Medium* > *Low* > *None*
H_4 Game Physical Engagement	*Medium* > *Low* > *None*

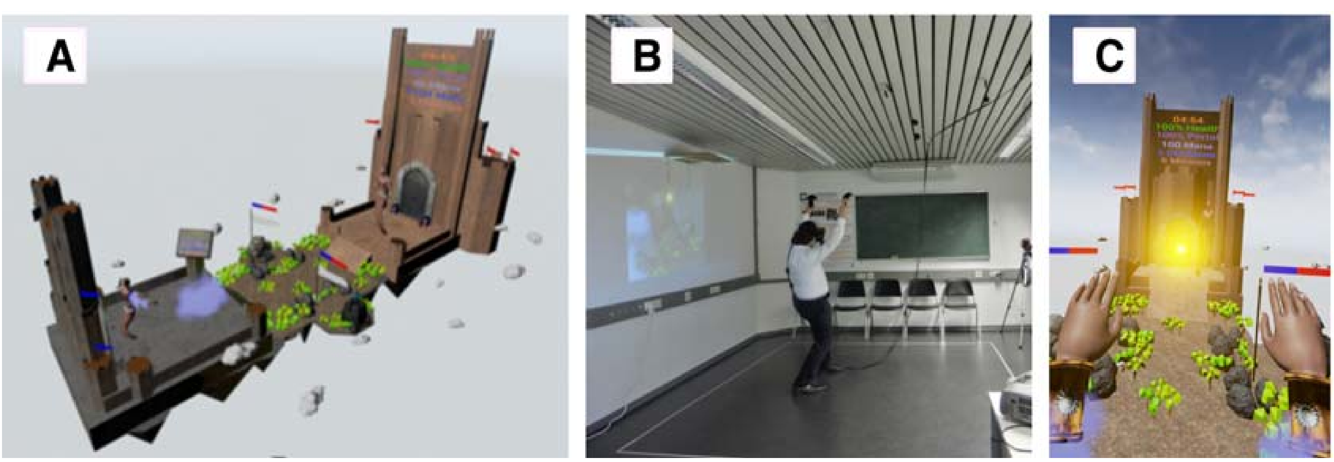

Figure 2: Experimental conditions and procedure for each experimental trial.

Table 2: Measures and Dependent Variables.

ID	Dependant Variables
	Subjective
DV1	Immersive Experience Questionnaire(IEQ) [14]
DV2	Illusion of Virtual Body Ownership Questionnaire Table 3 [37]
DV3	Simulation Sickness Questionnaire (SSQ) [16]
DV4	Demographic and VR Previous Experience Questionnaire
	Objectives
DV6	*Game Physical Engagement Metrics*
DV6-1	Distance Covered by Player Character
DV6-2	Distance Covered by Head
DV6-3	Distance Covered by Hands
DV7	*Game Performances Metrics*
DV7-1	Winning the match
DV7-2	Number of time Killed by GOD
DV7-3	Number of time Killing GOD
DV7-6	Number of time Destroying Portal
DV7-7	Percentage of Missed Shots
DV7-8	Average Time Successfully triggering Special attacks
DV8	*Game Focus Metrics*
DV8-1	Percentage of Time looking at the GOD
DV8-2	Percentage of Time looking at the Minions
DV8-3	Percentage of Time looking at the virtual body

Table 3: IVBO Questionnaire [37].

ID	**Question**
1	*myBody* I felt as if the body I saw in the virtual mirror might be my body
2	*myBodyParts* I felt as if the body parts I looked upon where my body parts
3	*humanness* The virtual body I saw was humanlike
4	*myMove* The movements I saw in the virtual mirror seemed to be my own movements
5	*myMoveEnjoy* I enjoyed controlling the virtual body I saw in the virtual mirror
6	*controlMove* I felt as if I was controlling the movement I saw in the virtual mirror
7	*causeMove* I felt as if I was causing the movement I saw in the virtual mirror
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	*newWeight* I felt an after-effect as if my body had become lighter/heavier
12	*newHeight* I felt an after-effect as if my body had become taller/smaller
13	*newSize* I felt an after-effect as if my body had become larger/thinner

3.1 Procedure

Participants were visually immersed in the virtual game world in a first-person perspective via the HMD. The Fig. 2 documents the structure of each experimental trial. It followed eleven main stages, from which two were quite important: the avatar embodiment and game understanding phases:

***VR Avatar Presentation and Calibration*:** During this phase, the *VB* presented to the player and adjusted to his/her body proportions. The procedure is semi-automatic and was realized with the help of a virtual mirror placed inside the virtual environment The presence of a mirror inside the environment reflecting the avatar's body is recommended for the user to be fully aware of their new appearance [43]. During the game phase, the mirror was not present. Realizing our experiment with the constant presence of a mirror will reduce the scope of our results. Having the game constantly providing a virtual mirror in its environment will create important constraints on any VR game design. In our setup, the plane mirror was just used for the avatar's body presentation, calibration, and acclimatization: *Low VB* condition, participants were asked if the virtual hands match their real hands' position and dimension. The experimenter then quickly adjusted their position and scale with hotkeys until satisfaction. The same procedure was applied to the *Medium* condition, however, another calibration system was performed to adjust the VB's torso and height. This procedure consisted of two main steps: i) Locating the player's mid-body position and size (i.e. hip height and abdominal depth) and ii) adjusting *VB* 's height, chest depth, and shoulder width. During the first phase, the player was asked to touch their body with the 3D Controller where the front of their belt is located and press a button. Then they repeated the same operation by locating the back of their belt. They were then looking in the mirror and asked to move around. The experimenter was then adjusting the VB's height and torso width by asking a series of question to the player. The adjustments were repeated until the player had a strong feeling that the VB was matching their location and dimension. We also asked participants to walk around in the virtual world to get familiar with wearing the HMD and navigate in the virtual environment.They were also instructed to report if anything felt unnatural or uncomfortable.

***VR Game Tutorial*:** During this phase the mirror disappeared and the player had to follow the instructions appearing on 3D message dialogue boxes in front of her/him. The tutorial included eight phases as depicted in Fig. 2. Afterwards, the experimenter asked, if the player had any questions, before recapitulating the game rules and making sure that the participant was feeling confident about the game rules and controls. On average, each trial took 45 minutes.

3.2 Game Design Choices

iGod is a single-player VR game which has been specially designed to constantly involve the player's hands and torso movements. It combines first-person shooter and battle arena game plays, mixing fast-paced action with strategy (see Fig. 1 and Fig. 2). As suggested by Sweetser and Wyeth [46], a combination of first-person shooter and strategy/role-playing gameplay could be more suitable for more generic game design studies and implications. First-person shooter games with a lifelike environment focus on the sense of immersion, often by requiring intense concentration and fast reactions. On the other hand, strategy and role-playing games focus more on the sense of control and impact on the game world. As shown in Fig. 3, the *iGod* game world involves two gods and their armies fighting above a battle arena separating their kingdoms' portals. One god is embodied by a human player, using a VR headset and 3D controllers. The other god (i.e. the enemy) is controlled by the game. A god has to defeat its opponent or destroy its base in order to be victorious. The game proposes different mechanisms to attack and defend: i) by guiding and helping an army of *Minions* ii) by engaging in direct combat with the enemy god using projectiles. The gameplay mechanics are *body-centered* and rely on constantly requesting hand or torso movements. The player uses the VR controllers to throw fireballs by simply pointing at a target and pressing the trigger button. Special attack can also be triggered by reproducing simple gestures with the VR controller (e.g. making a circle or straight line). The player can also attack by picking up and throwing minions on the battlefield. The player also possesses a special defense body-

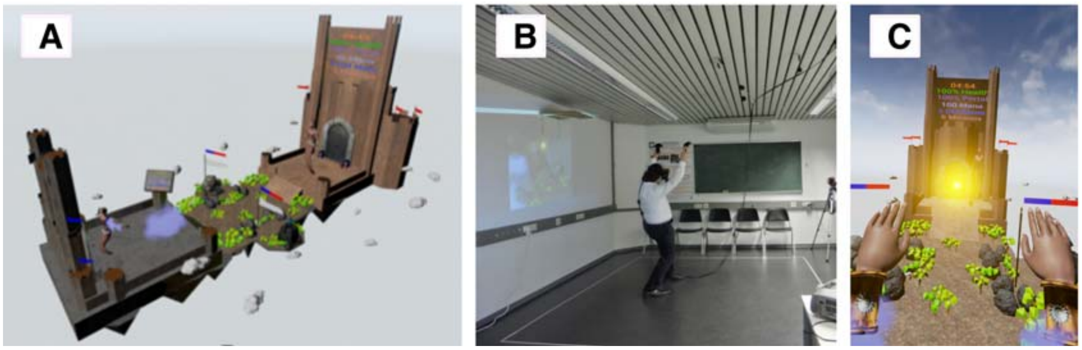

Figure 3: Game Overview: (A) The game environment, (B) a player embodying a god and trigger attacks (C) by performing special gestures.

based mechanism: a shield, fixed on their torso and protecting their upper body. The shield is breakable and bursts into pieces when completely damaged. Players also have the possibility to deflect incoming projectile, by hitting them with their virtual hands. In order to synchronize visuomotor stimuli, haptic feedback is generated (i.e. rumbling vibrations) for each body-environment interaction (such as deflecting a projectile, receiving damage or grabbing minions).

This game has multiple advantages for our study. Firstly, it can be played with or without an avatar body representation. Without visible body parts, the player can still interact via the virtual representation of the VR controllers and the virtual shield. Secondly, its gameplay requests a constant awareness of body positions. The player has multiple opportunities to look at her/his body during gameplay: i) move hands to throw and divert projectiles, ii) perform gestures to trigger special attacks, iii) walk, dodge and crouch to avoid projectiles, pickup up minions, charge mana energy in the mana cloud and iv) looking at the own body is also encouraged by indicating the player's health using the shield. As the player loses a life, the shield accumulates cracks and eventually breaks.

3.3 Software and Hardware

The *iGod* game has been developed on the top of the Unreal Engine 4 TM. It runs at an average of 89 frames per seconds for all experimental avatar conditions. The *GestureTrackerVR* plugin from the Unreal Marketplace was used to program and detect the player's gestures for special attacks. The hardware setup consisted of one PC station (Intel Core i7-6700k 4.0 GHz CPU, 16 GB of RAM, Nvidia GeForce GTX 1080 Graphics card). As depicted by Fig. 3 (b), *Players* were visually immersed in a virtual environment using the HTC Vive stereoscopic Head-mounted display (HMD), with a field of view of 110° nominal, a resolution of $1080x1200$ pixels per eye, and a refresh rate of 90Hz The player's hand motions were captured using the two wireless motion tracked controllers provided by the HTC Vive headset. These controllers also include trackpads, triggers and grip buttons inputs. Haptic feedback is also possible (by controlling vibrations intensity and frequency). The overall play area is a 3 x 3 x 2.5 meters volume. For a higher freedom of movement, cables were fixed to the ceiling using a system of retractable cables. HDM cables were also clipped to the player's clothes using simple fold-back clips. The cost of the setup is approximately 4000 Euro.

4 Results

Our total sample consisted of 75 participants, divided into three groups of twenty-five participants per condition. The mean age of the participants was 21.1 ($SD_{age} = 2.08$), 49 of the 75 were female. None of them had severe visual impairments, all of them were students and forty-eight of them had previous experience with VR. They used a PC regularly ($M = 5.89$ where 1 was not at all and 7 was very often, $SD = 1.24$). No participants were sorted out due to high simulator sickness values. However, six participants had to be excluded due to technical problems or a misunderstanding of the experimental procedure. Thus, the effective end sample size was $n = 69$, with an average age of $M = 21.2$ years old ($SD = 2.11$).

H_1 **Virtual Body Ownership Rejected**: The questionnaires scores are represented by Fig. 4. One-way ANOVAs for all questionnaire items did not reveal any significant divergence. We applied the TOST-method ('*two-one-sided-tests*'), which is a common way to test the equivalence of two or more samples [38]. Significant differences were found for the *MyBody*, $p = .048$ and *OwnOtherBody* ($p = .033$) between the conditions invisible body and the one with the highest number of visible body parts. Therefore, an equivalence between those items can be assumed for the *None* and *Medium*

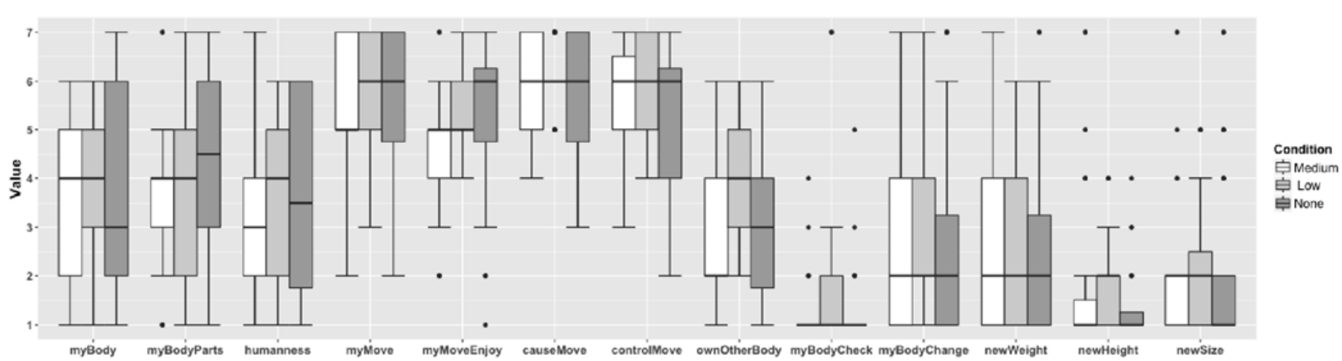

Figure 4: Box-plots of the Illusion of Virtual Body Ownership results (7-points Likert Scales - see Table 3 for associated questions).

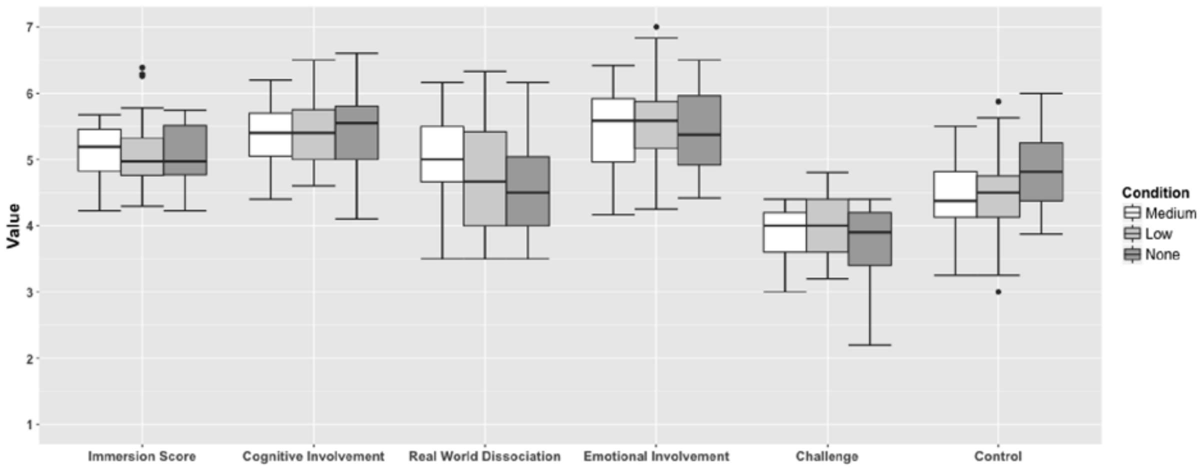

Figure 5: Box-plots of the Immersive Game Experience results (7-points Likert Scales).

condition. This is interesting as it may suggest that VR game designer could decide to provide no virtual body or a more coherent one without affecting the feeling of having a virtual body. Further experiments should explore if the presence of less coherent virtual body representation (i.e. just floating virtual hands not connected to any other body parts) have a different effect on body ownership.

H_2 **Game Experience Rejected**: The Fig. 5 is summarizing the Immersive Game Experience dimension scores obtained for each condition. One-way ANOVAs for all items did not yield any significant differences between the different conditions.

H_3 **Game Performance and** H_4 **Physical Engagement Rejected** : One-way ANOVAs yielded only two significant results on our*game metrics*. We detected a difference in how often the players looked at themselves ($F(2,66) = 10.18$, $p < .001$) and in how often the players looked at other things that are not minions, the enemy or themselves ($F(2,66) = 11.59$, $p < .001$). Post-hoc t-Tests indicated that students with a Medium body ($M = 23.02$, $SD = 20.75$) looked significantly more often at their body and hands than students without a body ($M = 6.84$, $SD = 7.55$), ($t(28) = 3.52$, $p > .001$, $d = 1.04$, $1-\beta = .97$). A t-test comparing the means of students with a Low body ($M = 25.6$, $SD = 14.7$) and those without a body also wielded significant results ($t(33) = 5.45$, $p > .001$, $d = 1.61$, $1-\beta = 1$). Players with the Medium body ($M = 27.1$, $SD = 19.8$) condition looked significantly less at things that are neither minions, the enemy nor themselves than players without a body ($M = 44.6$, $SD = 18.5$), ($t(44) = -3.09$, $p > .01$, $d = -.91$, $1-\beta = .92$). The same applies to players with a Low body ($M = 20.7$, $SD = 13.1$), ($t(40) = -5.04$, $p > .001$, d=-1.49, $1-\beta$=1).

5 Discussion

Overall, no significant differences were found between our three *VB* conditions. Consequently, all of our hypotheses must be rejected. Besides the fact that players were aware of, and observing their avatar body in the *Low and Medium* conditions, it did not affect their virtual body ownership, game experience or performance. Contrary to predictions based on previous work on avatar embodiment, avatar body invisibility seems to be less important than expected. Our results tend to confirm the hypothesis of Murphy [27] whereby the level of immersion in a VR game is mostly driven by *(1) sensorial immersion* and *(2) a well-calibrated motion control* allowing a high sense of control over objects and agents in simulated space. The lack of focus on the avatar body could also be explained as a normal side effect of *autotelic* activities, creating a strong form of enjoyment qualified as *flow* [44], or *game flow* [46] for digital games. The *flow* is an experience ”*so gratifying that people are willing to do it for its own sake, with little concern for what they will get out of it, even when it is difficult or dangerous*”. *Game flow* is the feeling resulting from the right combination of concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction in a digital game. One important effect of the *game flow* is that it creates a feeling where the player is totally immersed in or absorbed by the game, causing them to lose awareness of everyday life or concern for themselves, and alters their sense of time [46]. The lack of significant results constitutes an interesting insight for VR game designers. Integrating a *VB* is not a negligible task and current consumer grade body tracking solutions are still limited while, as a potentially desired outcome, a *VB* did not significantly affect the player's experience or performance.

Table 4: Game Metrics main results - Player Movement and Focus Quantification (significant results indicated in bold).

ID	Variable	Medium	Low	None
DV6	Game Physical Engagement Metrics (in meter)			
DV6-1	Distance (Player)	*M*: 56.71, *SD*: 32.53	*M*: 62.85, *SD*: 30.96	*M*: 65.94, *SD*: 36.95
DV6-2	Distance (HMD)	*M*: 53.32, *SD*: 33.74	*M*: 58.69, *SD*: 31.78	*M*: 61.73, *SD*: 36.71
DV6-3	Distance (Hands)	*M*: 243.19, *SD*: 131.74	*M*: 268.74, *SD*: 122.73	*M*: 272.83, *SD*: 119.15
DV7	Game Focus Metrics (in percentage of game time)			
DV8-1	Looked at (Self)	*M*: 23.02, *SD*: 20.75	*M*: 25.69, *SD*: 14.77	***M*: 6.84, *SD*: 7.55**
DV8-2	Looked at (Enemy)	*M*: 5.99, *SD*: 6.81	*M*: 4.23, *SD*: 3.57	*M*: 5.39, *SD*: 4.17
DV8-3	Looked at (Minions)	*M*: 43.84, *SD*: 22.87	*M*: 49.32, *SD*: 14.85	*M*: 43.09, *SD*: 20.05
DV8-4	Looked at (Other)	*M*: 27.14, *SD*: 19.89	*M*: 20.76, *SD*: 13.20	***M*: 44.68, *SD*: 18.53**

Table 5: Excerpt of players' comments.

Low Number of Visible Virtual Body Parts:
The hands make you feel like you are in the virtual world
The hands have contributed to the feeling of being really there
The hands really make you feel like you are there
Hands gave me the feeling of being there, even if "my" body was missing
Medium Number of Visible Virtual Body Parts:
The fact that I could see my virtual body made the experience more real
The virtual body give me the feeling of actually being in the virtual place
The fact of fitting your body exactly to the character and seeing "your" hands and, chest gives you the feeling that you are really the character
The adaptation of the avatar to my body definitely helped

5.1 Limitations

There are factors which potentially had undesired cross-effects on our results. Although not significant, the low scores for the *Medium* condition on the *acceptance* IVBO items (*myBody*, *myBodyParts*, and *humanness*) could indicate the existence of an *uncanny valley* effect as in [23], degrading the overall experience. Also notably, the *no body* condition still included virtual representations of the game controllers. Such controllers can still be integrated into the body schema due to the visuomotor synchrony despite their non-body part appearance. Hence, we cannot guarantee that this condition was always perceived as the complete absence of a *VB* . It minimized it w.r.t. the other two conditions while still providing the minimal means necessary for an effective gameplay. The limited tracking capacity, in terms of body part coverage, could also explain the lack of effects observed. The recent availability of additional tracking devices for VR game platforms (such as the HTC vive tracker [7]), is now opening the possibility to integrate more accurate and complete *VB* in games with additional body limb tracking (e.g., foot, elbow, torso). Therefore, replicating our experiment with *VB* using accurate torso, legs and feet tracking would be necessary. The fact that the *Real World Dissociation* in Fig. 5 seems to increase with higher body visibility is also encouraging for further research. The fact that 22% of participants explicitly mentioned that their virtual body parts improved their overall game experience is also promising (see examples of participants' comments in Table 5). The lack of significant results could also be explained by the body ownership questionnaire focusing on perception with a mirror, rather than inside a game. Our experiment would benefit from additional measurement techniques, such as qualitative feedback collected through think-aloud and video analysis as in [40]. Additionally, as suggested by [32], we could ask participants to provide affordance perception and body size estimations, where the change is biased by the size of the virtual body [32]. The *game flow* questionnaire based on concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction, could also be useful to correlate *flow* and body ownership perception [44].

6 Conclusion

This article reported a systematic evaluation of the impact of the number of virtual body parts in a VR game context on psychophysical effects known to be affected by avatar embodiment. We compared three avatar conditions, one without body part representation against a low and a medium number of visible body parts. Contrary to predicted effects from previous work on avatar embodiment, our results did not confirm any significant advantages or disadvantages of the degree of avatar body visibility completeness on said effects. This tends to confirm the strong "task performance" aspect of digital games, where control efficiency is paramount and can overcome perceptual effects. Our results also contribute to the debate of the relevance of top-down vs bottom-up factors for avatar psychophysical effects.

Our future work includes the replication of this experiment with full-body tracking, including legs, feet, and torso. The possible negative physical and psychological effects of body substitution should also be considered and carefully researched. Specifically, because players experiencing greater immersion in violent games may be more likely to display real-world aggression [33], and emotionally unstable individuals may be the most vulnerable to violent video games [15]. Novel types of diegetic interfaces can be fixed on *VB* parts, such as energy bars, injury. Especially, because they have been shown to increase cognitive involvement and sense of control [12].

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