Understanding the Impact of Coherence between Virtual Representations and Possible Interactions on Embodiment in VR: an Affordance Perspective

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Figure 1: Ghostly hand (left) and gloved hand (right) in the virtual manor environment of the experiment.

ABSTRACT

The way users interact with Virtual Reality (VR) environments plays a crucial role in shaping their experience of embodying an avatar. The perception of avatars significantly influences users' behaviour based on stereotypes, a phenomenon known as the Proteus effect. Moreover, understanding how virtual representations suggest possibilities for action (affordances) has attracted considerable attention in the human-computer interaction community. The aesthetic features of avatars may thus signify false affordances, conflicting with users' expectations and impacting perceived plausibility, presence and embodiment. To explore this topic, this research focuses on the perception of virtual hands, comparing ghost-like and gloved representations by leveraging their affordances. This paper presents a preliminary assessment of avatar-related affordances, and the protocol of the follow-up VR experiment. Our future contribution lies in a documented study on the coherence between user representation, suggested affordances and actual agency, aiming to inform designers and researchers on how it could enhance VR qualia.

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CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *User studies.*

KEYWORDS

virtual reality, avatar, embodiment, presence, affordance, plausibility

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1 INTRODUCTION

Interactions offered by Immersive Virtual Environments (IVEs) are what allow users to process through the simulated space, for example by navigating or manipulating objects. Such interactions are oftentimes carried out through virtual self-representations, commonly referred to as *avatars*. In this context, designing interactions that involve users' self-representation can impact their experience and attitude. It has been proved through the Proteus effect [46] that virtual representations of users influence their behaviour depending on the stereotypes they may be associated with. Furthermore, our natural and cultural environments offer possibilities for actions that users could perceive, which has been theorised as *affordances* by Gibson [13]. This concept was introduced to the domain of Human-Computer Interactions (HCIs) by Norman [30] who states: "When affordances are taken advantage of, the user knows what to do just by looking; no picture, label, or instruction needed". In this perspective, the use of affordances has attracted attention from the HCI community which praises their use [8, 10]. Nonetheless, Alkemade et al. [1] warn about the power of affordances when dealing with Virtual Reality (VR) applications: "a model of a physical hand can [...] be confusing if it does not support the perceived affordance". Indeed, the extra-ordinary features offered by IVEs in terms of virtual representations design may trigger the perception of "false affordances" that would go against users' expectations when they would try to take advantage of it. For example, being provided with an avatar having a ghost-like appearance while not being able to go through virtual elements could cause an incongruency with users' expectations [24]. In such a case, the representation would suggest possibilities incoherent with the virtual world design [36], which in turn may results in negative impacts on the experience of users being embodied in a virtual body [22], or on their sense of presence in the IVE [39]. Conversely, the absence of some physical features, inherently difficult to reproduce in VR, like accurate physically-based interactions, has proved to negatively affect the sense of embodiment [42]. Manipulating users' virtual representation could hence serve justifying the absence of physically-based interactions in the IVE and limit the alteration of the aforementioned subjective properties like embodiment and presence, commonly referred to as *qualia*. Consequently, by centring our approach around the perception of virtual hands, that are the main instrument of our agency in VR, our work aims at answering the following questions: can interaction possibilities incoherent of the virtual hands' appearance impair the experience of being embodied in an avatar and immersed in a virtual environment? Can perceived avatar-related *signifiers* of affordance justify the interaction possibilities while preventing the degradation of their experience?

This paper outlines our approach to lead this research. The subsequent sections are organised as follows: firstly, relevant literature about avatar-related VR qualia, affordances and plausibility is presented. Secondly, we introduce an experimental protocol based on a preliminary study meant to assess the affordance perception of three virtual hand representations. Finally, we conclude on these preliminary results and outline our experimental perspectives. By doing so, and to the best of our knowledge, we propose the first documented study on the coherence between the users' virtual representation, their perception of their virtual body, and their potential for action in the virtual space. Our current contribution lies in the methodology we employed to assess the intended perception of avatar-related affordances through an online questionnaire. It successfully demonstrated that our ghost-like hand shader design afforded passing-through objects and that our gloved hands design would rather afford colliding with objects.

2 RELATED WORK

2.1 Embodiment in Immersive Virtual Reality

In VR, users often navigate in immersive environments through embodied virtual representations commonly known as avatars. Avatars can vary from virtual hands to a complete virtual body [17]. Kilteni et al. [22] proposed a conceptualisation of the sense of embodiment (SoE) in VR, or how the properties of the virtual body are processed as if they were those of the biological body, which comprises: *Self-Location*, denoting "one's spatial experience of being inside a body" (distinct from being in the virtual world) [9, 22]; *Agency*, signifying the sensation of having complete motor control over the virtual body, encompassing the intention of actions [5, 18]; *Body Ownership*, referring to the self-attribution made to the virtual body [23, 40].

The Sense of Embodiment (SoE) is sensitive to bottom-up influences, like visuo-tactile stimulation [6] or visuo-motor synchrony [22, 32], but also to top-down factors like the avatars' shape [2, 14], realism [43], as well as to individual differences between users [11]. However, achieving higher embodiment by changing avatars' appearance is not trivial, as it may in turn affect the way users interact with the virtual environment. Indeed, previous work demonstrated that a realistic hand elicited more body ownership but significantly decreased performances in different tasks compared to abstract and iconic ones [2]. Similarly, Lin and Jörg [26] noted the successful induction of ownership over non-realistic virtual hands, but still with a stronger effect for the realistic ones. Experiencing high SoE has numerous benefits such as fostering body integrity awareness [15]. Another psychological consequence of the avatar appearance and embodiment lies in the Proteus Effect, meaning how one conforms its behaviour to the stereotypes suggested by the virtual representation [46]. Despite this effect primes behavioural changes [21], it may also affect cognitive performances [3, 16]. Thus, the user experience may be impacted depending on what the avatar appearance suggests.

2.2 The Concept of Affordances

When it comes to the perception of interaction possibilities through the avatar, the concept of affordances may appear as well-suited. Theorised by Gibson [13] and introduced to the field of HCI by Norman [30], affordances refer to the potential interactions offered by the object of interest. For instance, a frisbee can be perceived as a throwable flying object or, when inverted, as a plate. Norman [31] contends that what we perceive as affordances are not the affordances themselves but rather signifiers. The use of affordances in IVEs has thus been advocated by the HCI community [8, 10, 27]. Yet, there are claims that the original theory of Gibson is not well suited to the rapidly evolving HCI field. Proposing a mediated-action theory, Kaptelinin and Nardi [20] reground the theory around "how humans act in their cultural environments, rather than [...] how animals act in their natural habitats", through culturally developed tools (technology). Hence, the authors introduce *instrumental affordances*, encompassing tool *handling affordances* and tool *effecter affordances*. As an example, a knife features both types of affordances in place of the handle (handling) that serves manipulating it, and the blade (effecter) to cut things.

Applying this perspective to avatars in VR, one can view them as a tool, what would in turn allow to shape users' perception by modifying their appearance [35], aligning with the approach of Joy et al. [19]. The latters, through a documented study about the perception of avatar-related affordances for VR interactions, unveiled an objective *affordance effect*: participants reacted faster when a cup's handle appeared before the hand they would use to grab it. Additionally, they varied the virtual hand type in a second study which proved to significantly affect the affordance effect and thus the perception of possible actions. However, despite they measured body ownership, they compared virtual hand types (with vs without fingers) that already presented significantly different perceived ownership levels in past literature [2]. Similarly, people using a virtual hammer prosthesis compared to realistic gender and colour matched virtual hands were less afraid of hitting dangerous objects [14], or controlling a realistic hand may lead to handle objects as carefully as if they were real and heavy [4]. Thus, establishing the impact of such affordance effect on body ownership given similar hand types remains underexplored. Especially, this could help characterising the influence of cues signifying affordances that are not actually present, akin to the concept of *false affordances* [12].

2.3 Coherence and Plausibility of the User Representation

Designers engaging in immersive VR interactions and harnessing affordances by altering avatar appearance may carefully consider plausibility. Slater [39] refers to this concept as the *Plausibility Illusion (PsI)*, denoting the illusion that virtual events seem real despite our awareness of their unreality. He introduces *Place Illusion (PI)* to refer to the sense of presence, meaning *being there* in the virtual environment [25, 41, 45]. He also emphasises the necessity of both PI and PsI to respond authentically to virtual stimuli. Skarbez et al. [37] expand on this theory by introducing the coherence as the objective concept shaping the subjective experience of PsI, alike immersion is framing PI [38, 39]. According to Skarbez et al. [37], presence is fully experienced through PI, PsI, social presence and the characteristics of the user. In addition, Latoschik and Wienrich [24] recently proposed the Congruence and Plausibility (CaP) model that extends the presence-oriented theory to broader eXtended Reality (XR) qualia like embodiment. From now on, understanding the role of plausibility in subjective VR experiences becomes crucial, as breaks in PsI can significantly impact VR qualia like presence [36]. Building up on the CaP model, Mal et al. [28] propose the Virtual Human Plausibility (VHP) approach to specifically assess, through questionnaires, the avatar's appearance and behavioural plausibility, as well as how plausible it is in the virtual world.

The concept of plausibility provides a fresh perspective on embodiment literature. Tao et al. [42] recently investigated the embodiment of physics aware avatars, that inherently display a mismatch with user's position when simulating physics, which proved to increase the perceived sense of presence and embodiment. However, this effect was not observed for the ownership dimension. Such enhancement may be partially attributed to the congruence and therefore PsI elicited by accurate physics simulation, despite a mismatch in self-location. This point is further highlighted by the work of Wentzel et al. [44] who demonstrated that proprioceptive mismatches did not affect embodiment. Additionally, recent studies suggest that task-related incongruencies may have a potent impact on plausibility, with ongoing investigations needed [7]. Similarly, Mal et al. [29] manipulated the avatar-environment congruence, wearing either sport or business clothing, in either a sport or business inspired virtual interior. They highlighted notable differences in perceived plausibility without a substantial impact on SoE and presence. Research on the impact of congruence (coherence) on XR qualia is sill in its infancy, requiring further exploration on the avatars' side to characterise its effect on top-down processing of perceptual cues in VR like virtual hand shaders for instance.

3 DESIGNED EXPERIMENT

Avatars being the instrument of our agency in virtual environments, their representation may convey false affordances, meaning possibilities for action and interactions that seem achievable but that are actually not carried out by the simulation. Such misalignment induces incongruencies, diminishing the plausibility of the scenario and which may, in parallel, impact critical VR qualia like presence and embodiment. Conversely, manipulating the users' representation could serve justifying the absence of anticipated features. Therefore, the proposed project aims at studying the impact of perceived affordances emerging from virtual hands through different shading methods that could depict their possibilities for action. This section presents the forwarded VR experiment we developed along with the complete preliminary study undertaken to assess candidate virtual hand representations and their affordances.

3.1 Virtual Scenario

We are planning to immerse participants in an interactive VR scenario using a Meta Quest 3 headset, powered by a desktop computer capable of running the application at a minimum frame rate of 90Hz. Participants will control virtual hands using the headset's hand tracking capabilities. The action will take place in a old manor (see Figure 1), where the embodied character is appearing. In this context, we would like to offer two different virtual hand representations as well as two different interactions, that would generate both congruent and incongruent configurations. The choice was made to investigate ghost-like and tangible representations (Figure 1) that both afford natural interactions to the user: a ghost hand would afford going through objects, while a gloved one would afford colliding with the environment. Additionally, only the tangible gloved hand would generate shadows. The participants will be seated before a wooden desk, and will be asked to carry out a task, that is still under development, and that would be coherently doable in either of the collision conditions. Finally, both representations could be considered as plausible in such an old manor environment.

3.2 Preliminary Study

Before running the actual experiment, it appeared critical to assess the virtual hand representations that would suggest the expected effecter affordances, meaning passing through objects for the ghost hand and colliding with them for the gloved one. A preliminary study was consequently carried out through an online questionnaire to assess the perceived affordances of three different virtual hands. The native Oculus hand shader (Meta's developer kit), a gloved hand appearance, and a ghost-like shader with vaporous Visual Effects (VFX) (Figure 2) were considered for this online survey. The choice to consider the Oculus shader for the preliminary study was two-folded: firstly to probe what a widespread semi-transparent hand shader afforded, and secondly to offer participants a third option that would avoid possibly biasing them with only two opposite representations. The affordances of the virtual hand representations were explored following a within-subjects design.

3.2.1 Online survey procedure for affordance assessment. Participants were informed about the anonymous nature of this online experiment and that answering it would assert their consent to the study. Demographics were then collected, including gender, age and participants' experience with VR using 5-point Likert scales (1-*"No experience at all (very few uses)"*; 5-*"Expert user (quasi daily uses)"*), as it may affect the answers about perceived affordances. Respondents were then asked to watch carefully three short video clips ($M = 10sec$) displaying virtual hands moving over the wooden desk in the manor environment, in a similar fashion. At the end of each clip, the virtual hands move downward rapidly, as if the user wanted to clap the hands on the desk, which ends the clip before the collision occurs. After each viewing, respondents were asked to indicate what would happen after the video clip was cut, on a 5-point Likert scale (1-*"The hands would likely go through the table"*; 5-*"The hands would likely lie on the table"*). The choice not to propose binary options was made to foster participants suggestive imagination and to avoid biasing them while still offering a middle-ground option. The video shots were presented in the following order: native Oculus shader, gloved hand, ghost hand. Finally, participants were expressly asked to justify each of their scores thanks to an open-ended item, so that highly valuable qualitative feedback could be gathered. Despite we did not randomise the presentation order of the videos in the context of a preliminary study, the collected qualitative insights will reinforce confidence in the quantitative results. More importantly, the follow-up experiment's conditions will be counterbalanced.

The survey was spread in various academic and student mailing lists across, but also on international professional social networks. The poll was available in French and English languages. Altogether, 91 people responded to the online survey. However, 4 respondents were removed from the study, either because their feedback was unusable/very poorly worded ($n = 3$) or because their response time was below the threshold of 1 min 30 seconds, which corresponds to the minimum response time when reading and watching carefully all elements ($n = 1$). In the end, 87 respondents (50 females, 37 males) aged from 19 to 65 ($M = 27.4$, $SD = 10.1$) were considered for the analysis. Their previous experience with VR was quite wide-ranging ($M = 2.24$, $SD = 1.18$).

3.2.2 Quantitative results. A statistical analysis was conducted to investigate the impact of the virtual hand representation on perceived affordance. Differences are considered significant for p-values below .05. The sphericity assumption was successfully checked ($p = .535$). However, the affordance scores significantly deviated from normality. Consequently, a Friedman's test was considered and showed a significant effect of the hand representation on the affordance scores ($\chi^2(2) = 117.7, p < .001$). Pairwise comparisons using Bonferroni correction revealed significant differences between all hand representations (all $p < .001$). As expected, the descriptive statistics show that the ghost hands were perceived to be the most likely to go through the desk ($M = 1.70$, $SD = .978$), and the gloved hands were perceived as the most likely to collide with the desk ($M = 4.17$, $SD = 1.08$). Interestingly, scores for hands using the native Oculus shader were average and widely distributed, which suggests an ambiguous type of representation ($M = 2.74$, $SD = 1.44$) (see Figure 3). Spearman's test did not unveil any correlation between the affordance score and prior VR experience.

3.2.3 Qualitative analysis. Qualitative feedback offers unique insights into participants' perception of the effecter affordances for the virtual hand representations. The authors carefully analysed the open-ended responses from the participants, cross-checked written items and grouped data. Overall, two categories of answers arose from the online survey which may be explained by the concept of affordances. Indeed, respondents either answered based on technology affordances, meaning what the VR technology allows in comparison to the real world, or based on the virtual hand effecter affordances, meaning what the hand appearance suggests about the interaction (see Figure 4). Each of these categories may be concerned with either justifying a perceived passthrough or collision behaviour. First of all, the native Oculus hand shader divided the participants on the perceived affordance. On the one hand, more than a third of the respondents ($n = 35$) stated that the hands would likely go through the desk by describing their appearance as "semi-transparent" (P4, $score = 1$), or even "non physically tangible, like a ghost" (P7, $score = 1$). Other respondents forwarded the absence of collision as a limitation of VR ($n = 15$). On the other hand, few people argued that it would clap on the desk as it is "logic" or "realistic" ($n = 5$), as if they transposed their experience of the real world to the VR one. Some finally argued for a collision behaviour using technology-related affordances ($n = 22$), like "colliders" (P33, $score = 4$), the finger tracking feature (P10, P37), or by stating VR aims at reproducing "reality" (P12, P18, P38). Regarding the gloved condition, participants' expectations about the interaction outcome was clear. They mostly expected the hands to clap on the desk using the opacity of the hands as an argument ($n = 65$), or the affordances of the technology for a few ($n = 9$), mostly arguing that VR must stick to reality. Overall, the hands texture elicited a "better sense of realism" (P44, $score = 5$), making them "less fantomatic" (P20, $score = 4$). The fact they were generating shadows on the desk may have also played a role ($n = 5$). However, despite some respondents were influenced by this appearance, they were leaning toward following technological affordances of VR ($n = 7$), by stating for instance "I remain convinced of my virtual presence" (P37, $score = 2$), or "nothing is really stopping them [in reality]"(P41, $score = 1$). Lastly, when the respondents watched the ghost hands clip, they almost unanimously stated that their "ghostly", "spectral", "vaporous" aspect markedly made them state it would go through the desk ($n = 73$). Very few people used the VR technology affordances as a primary argument to justify it would either go through the desk ($n = 3$) or clap on it ($n = 4$).

3.2.4 Discussion. As takeaways, it appears the default hand shader affordance was ambiguous compared to the two other conditions (see Figure 3). Quantitative trends are supported by a shift in response schema, as the respondents who argued using technology

(a) Default Oculus shader **(b) Gloved hand** **(c) Ghost hand**

Figure 2: Virtual hand conditions used in the online survey.

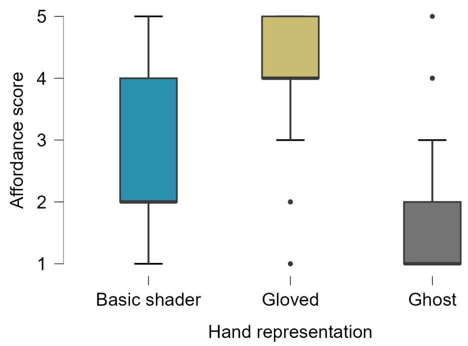

Figure 3: Boxplots for the affordance scores

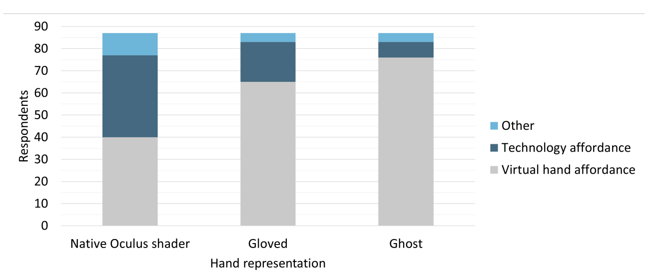

Figure 4: Qualitative feedback distribution

affordances in the native semi-transparent shader condition finally moved to a hand affordance justification for the two remaining conditions (see Figure 4). In fact, this visual affordance scheme was followed by nearly all respondents for the ghost and gloved conditions, which matches our expectations. The appearance argument for the ghost hands was interestingly more widely used to justify the perceived affordances than for the gloved hand. This may be explained by the fact the ghost appearance affordance of passing through objects strongly aligns with one of the primary technological affordance of VR, namely the lack of haptic feedback. All in all, this qualitative analysis together with the quantitative one gives us confidence that the virtual hands we designed provide suitable affordances for the forthcoming study. One may question the generalisation of the findings made with a ghost-like hand, that would come out of the follow-up experiment, to a broader context. However, this choice gives the design advantage of an abstraction from the gender and skin colours considerations for embodiment, while allowing to pave the way of research on embodied affordances with a concrete example of transparent hand representations, commonly used in VR.

3.3 Follow-Up VR Experiment

Following the encouraging results presented in section 3.2, we plan to carry out the VR experiment using the hand conditions we validated based on the online survey. Below is introduced the intended experimental protocol and associated measurements.

3.3.1 Design. This study will be conducted using a 2 x 2 mixed factorial design. We will compare two hand representations (ghost vs gloved) as a within-subjects variable by counterbalancing conditions. The collision mode will be explored as a between-subjects variable (passthrough vs physics-based). This design choice will result in a comparative study of interactions carried out by two different hand models suggesting antagonist affordances.

3.3.2 Procedure and Measurements. To begin with, participants will be invited to complete a pre-experiment questionnaire to collect demographics, as well as self-reported video game and VR experiences. They will be asked to sit on a chair after receiving instructions for the experiment. At the beginning of each session in the virtual environment, they will observe the room in which they are located and familiarise themselves with their virtual hands. Then, they will have to perform the planned task that will be common to all conditions. In light of the literature review, an object manipulation task or eventually a response-to-threat one are considered for this study. The collision mode condition will not be explicitly told to the participants in order them to experience the congruent or incongruent configuration as suggested by the hand representations. The completion time for each session will be recorded.

After each session in the IVE, participants will be asked to complete a post-experiment questionnaire to assess their sense of body ownership, sense of agency, and the perceived change in their body schema based on the Virtual Embodiment Questionnaire (VEQ)

[33]. A measure of plausibility will also be included through the VHP scale [28], as well as a measure of presence through the IGroup Presence Questionnaire (IPQ) [34]. A semi-structured interview will be carried after the immersion sessions focusing on the comparison between the two models in order to collect qualitative feedback.

3.3.3 Sample size estimate. We used the G*Power software to provide an estimation of the total sample size required to perform the statistical analysis. The assumption was made of a medium effect size ($\eta_p^2 \geq .06$, effect size $f = .14$), for the different qualia scores. With a significance $\alpha = .05$ and a power $(1 - \beta) = 0.8$, the minimum total sample size needed is 34 across all groups.

3.3.4 Hypotheses. In light of the literature review, it may be hypothesised that virtual hand false affordances negatively affect (H1) plausibility, (H2) presence and (H3) embodiment. The presented protocol allows investigating such hypotheses through a mixed repeated measures Analysis of Variances (ANOVA) focused on the interaction effects between the independent variables.

4 CONCLUSION AND FUTURE WORK

We introduced an experiment to investigate how the coherence between avatar appearance, the potential for action it suggests, and the actual interaction possibilities could impact the presence, embodiment and plausibility in virtual reality. We argued that such an investigation through the prism of the affordances theory may bring a novel eye on what virtual character appearances suggest. This implied to assess the perception of such affordances, preferably prior to any immersion in VR. We successfully took this first step through an online survey considering three virtual hand representations: a native Oculus semi-transparent shader, a gloved hand , and a ghost-like one (Figure 2). Additionally, the qualitative analysis emerging from this survey gave us confidence that users will be able to perceive the expected affordances for the gloved and ghost conditions. This constitutes a step toward asserting the online test of affordances is a good practice for researchers and interaction designers. However, this was only a first step toward answering our research questions. The forthcoming user study will help further assess the perception of interaction affordances through a between-within counterbalanced experimental design. Such outcomes will be meant to inform researchers, designers and developers on the potential impact of perceived affordances of users' virtual representations on presence, embodiment and plausibility in virtual reality.

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