Impact of Avatar Facial Anthropomorphism on Body Ownership, Attractiveness and Social Presence in Collaborative Tasks in Immersive Virtual Environments

Charlotte Dubosc[a,1,*], Geoffrey Gorisse[a,1,*], Olivier Christmann[a], Sylvain Fleury[a], Killian Poinsot[a], Simon Richir[a]

[a]Arts et Métiers Institute of Technology, LAMPA, 53810 Changé, France

Abstract

Effective collaboration in immersive virtual environments requires to be able to communicate flawlessly using both verbal and non-verbal communication. We present two experiments investigating the impact of facial anthropomorphism on the sense of body ownership, avatar attractiveness, social presence and performance in two collaborative tasks. In the first experiment participants have to solve a construction game according to their partner's instructions using three avatars presenting different facial properties. Results reveal no significant difference in terms of body ownership and social presence, but demonstrate significant differences in terms of attractiveness and completion duration of the collaborative task. Unexpectedly, correlation analyses also reveal a link between attractiveness and performance. The more attractive the avatar, the shorter the completion duration of the game. Our second experiment was designed to investigate further the potential impact of the task carried out on the sense of social presence using the same avatars. While we observed a very high sense of social presence in both tasks (asymmetric collaboration and negotiation) with every avatar, our results did not reveal significant difference between the three conditions. However, we observed statistically significant differences between the two task types. The scores of the co-presence and of the perceived message understanding dimensions of social presence were higher during the negotiation task. The sense of social presence appears to be task sensitive, especially when non-verbal communication becomes more important during face-to-face interaction in immersive collaborative virtual environments.

Keywords: Virtual Reality; Avatar; Anthropomorphism; Realism; Body Ownership; Social Presence.

1. Introduction

Understanding the processes allowing people to collaborate in immersive virtual environments is a current challenge at the crossroad of computer science and psychology for virtual reality researchers. It is necessary to understand such mechanisms to develop applications allowing users to interact together through virtual characters (avatars) [1] while providing a satisfying user experience. Several studies aim at investigating the impact of multisensory integration (e.g. visuomotor and visuo-tactile synchrony [2]) or virtual characters' properties such as realism, eye gaze or lip synchronization relying most of the time on human characters [3, 4, 5, 6]. Such research uses eye tracking technologies and/or full-body tracking. However, there is a technological gap between lab experiments and most available virtual reality applications. In this context, we decided to conduct an experiment based on lightweight setups avoiding relying on full-body tracking to control virtual legs and arms to be in line with a lot of use cases and mass market virtual reality devices. We designed a study involving three robotic avatars allowing to use non-human body schema (no legs, and floating hands) presenting different anthropomorphic facial properties (Figure 1).

We conducted a first experiment to investigate if more realistic anthropomorphic facial properties favor the attractiveness of virtual characters [7, 8, 9] as well as users' sense of body ownership [10] and social presence [11, 12]. This experiment also aims at investigating if such facial properties allow for better performance thanks to an improved adequacy between verbal and non-verbal communication in an asymmetric collaborative situation where participants must follow their partner's instructions alternately to solve a puzzle game. While we observed significant differences in terms of attractiveness and performance in this first experiment, we wanted to investigate further the way the type of task carried out could affect participants' sense of social presence using the same avatars. Therefore, we report a second experiment where participants performed a negotiation task. These tasks were designed to match potential collaborative situations and use cases of remote collaboration in immersive virtual environments.

The next section presents a state of the art on body ownership, attractiveness and social presence as well as an overview of several factors influencing communication and collaboration in immersive virtual environments. Section 3 presents our three avatars and the setup used in both experiments. The first experiment is reported in Section 4 and the second experiment in Section 5. Section 6 presents the limits of these studies and potential future work. Section 7 concludes and summarizes our contributions.

---

*Corresponding authors
Email addresses:* `charlotte.dubosc@ensam.eu` (Charlotte Dubosc), `geoffrey.gorisse@ensam.eu` (Geoffrey Gorisse)
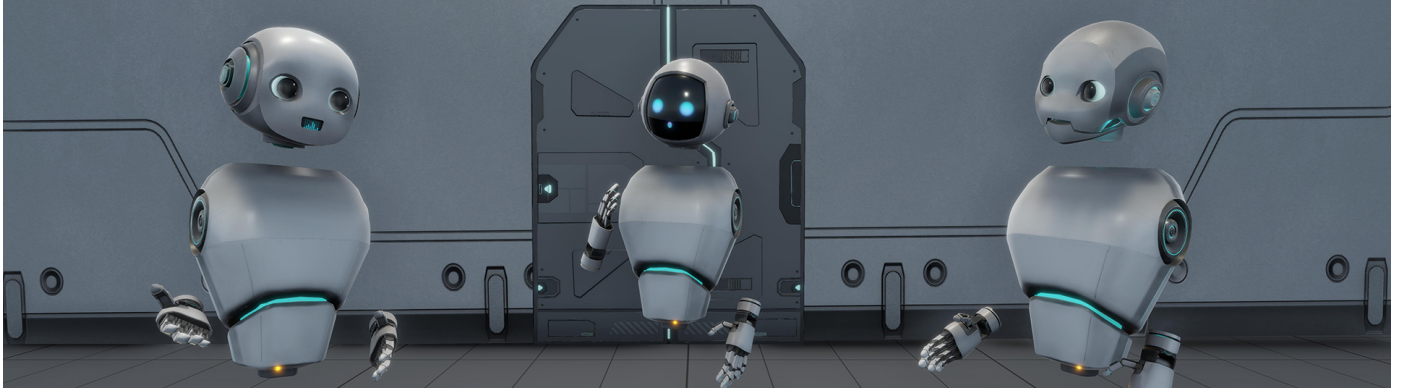[1]Both authors contributed equally to this manuscript.

Figure 1: Screenshot of the three avatars embodied by the participants in the immersive collaborative virtual environment of the experiment.

2. Related Work

2.1. Body Ownership

The sense of body ownership is part of the embodiment process in virtual environments. The sense of embodiment refers to the feeling of being located inside, of owning and controlling another body. According to Kilteni *et al.* [13], the sense of embodiment towards a virtual body could be defined as the sense that emerges when the virtual body's properties are processed as if they were the properties of one's own biological body. Three dimensions are identified as part of the sense of embodiment in immersive virtual environments:

- Self-location, corresponding to a determinate volume in space where users feel located. The sense of self-location is mainly affected by bottom-up factors such as visuotactile synchrony [14, 15] or perspective [16, 17, 18].

- Agency, defined as the *"global motor control, including the subjective experience of action, control, intention, motor selection and the conscious experience of will"* [19]. Bottom-up factors also impact the sense of agency. For instance, visuomotor synchrony appears to be a very effective contributor [17, 20, 21, 22]. The sense of agency is also correlated with an internal locus of control [23].

- Body ownership, which refers to one's self-attribution of a body [13]. Both bottom-up [24, 2, 10] and top-down factors [20, 25, 26, 27] can impact the sense of body ownership.

While self-location and agency are important to embody avatars in virtual environments, our study focuses especially on the sense of body ownership. According to previous work, none of our variables are supposed to impact other dimensions of the sense of embodiment. The famous Rubber Hand Illusion (RHI) paradigm [28] demonstrated that it was possible to induce a proprioceptive drift through synchronous visuotactile stimulation between a real and a fake hand resulting in a sense of ownership over the fake limb. Based on such results, the same paradigm has been replicated in virtual environments [29] demonstrating that multisensory integration (e.g. visuomotor and visuotactile synchrony) [2] is a critical contributor to the emergence of a sense of ownership that allows the embodiment of avatars with different morphological and demographic characteristics [30, 31, 32, 18]. Moreover, pre-baked facial animations of non-photorealistic virtual humans can induce an enfancement illusion in which users tend to believe that virtual characters' faces are their own faces [33]. Nevertheless, it has also been demonstrated that morphological similarities can impact positively the sense of ownership [27, 26, 25, 20].

In the frame of our experiment, we expect participants to be able to embody every robotic avatar thanks to visuomotor synchrony (head, torso and hand positions and rotations), but that the different facial properties may impact the sense of ownership. In addition, it should be noted that sharing a virtual environment with other users does not impact the sense of embodiment [34].

2.2. Attractiveness

It is acknowledged that attractiveness of avatars has a significant impact in both single and multi-user applications. It can impact the way participants evaluate and to what extent they feel comfortable using their avatar [9]. It can also affect the way people behave and interact when they are exposed to social situations in immersive virtual environments [35] or even their performance in massively multiplayer online games [36]. Several characteristics can affect attractiveness evaluations of virtual characters. For instance, previous studies demonstrated that realism is not a good predictor of attractiveness [7, 8]. The work of Zell *et al.* [7] illustrates the importance of consistency between the level of stylization of the shapes and materials of the characters, with inconsistencies having a negative impact on their attractiveness. The work of Fleming *et al.* [8] also reveals the significant influence of shapes and proportions. Their results showed that attractiveness evaluations are more favorable for avatars with an intermediate level of stylization compared to the original and highly realistic scanned 3D models. However, McDonnell *et al.* [37] demonstrated that both highly realistic and highly abstract character could be rated as more appealing, which may be explained by the occurrence of an uncanny valley effect for intermediate conditions [38, 39]. Therefore, avatar visual fidelity has to be taken into account when designing virtual characters as it affects the way users behave when controlling

2

and interacting with their avatar [9, 20]. According to Garau [5], visual fidelity of virtual characters can be categorized in three criteria:

- Anthropomorphism (*non-humanoid <-> humanoid*): Morphological characteristics of the virtual character.

- Realism (*cartoonish <-> photorealistic*): level of detail of the mesh and textures of the 3D model.

- Truthfulness (*does not look like the user <-> looks like the user*): degree of similarity between the user and the virtual character [40].

Based on previously reported studies, it is acknowledged that realism [7, 8, 37] and truthfulness [9, 20] can affect users' perception of virtual characters. To further complete such results we are interested to investigate if facial anthropomorphism impacts avatar attractiveness evaluations in immersive collaborative virtual environments.

2.3. Communication in Collaborative Virtual Environments

If visual fidelity is an important factor to consider when dealing with attractiveness, it has also been demonstrated that behavioral fidelity, through gestures and facial expressions, has to be taken into account to allow for a flawless communication in virtual environments [5, 41]. Social interactions rely on both verbal and non-verbal communication. While verbal communication contributes to social interactions in virtual environments [42, 43], this study does not focus on this aspect as it is not directly linked to virtual characters' facial properties. However, non-verbal communication and collaboration could be affected by the anthropomorphism level. The more realistic facial properties are, the more users' real expressions can be reproduced.

Non-verbal communication includes gestures, body postures, facial expressions, micro-expressions and can be either conscious or unconscious. Used in combination with verbal communication, gestures add an emotional valence and help to communicate. Regarding virtual characters, it has been demonstrated that more accurate gestures allow for better non-verbal communication [44]. However, anthropomorphism can impact the way users perceive virtual characters' actions and movements [45]. In addition, unconscious and therefore uncontrolled expressions have been the subject of studies aiming to investigate the impact of virtual agents' expressiveness and their ability to communicate emotions [46, 47]. Current mass market virtual reality devices do not allow users' facial expressions to be recorded and transferred to their avatar unless a custom headset is used [48]. Nevertheless, recent research demonstrates that it is possible to enhance self-identification using pre-baked animations for facial expressions [33]. Gaze animations can also impact users' perception of communication [49] and provide visual clues concerning the attention state of their partner [3, 4, 50]. According to these studies, a more realistic eye gaze implementation leads to higher communication potential and more realistic responses during dyadic interactions. Overall, conscious non-verbal communication (gestures and facial expressions) appears to improve users' sense of co-presence in virtual environments [51].

2.4. Social Presence

The sense of co-presence is part of the sense of social presence and is essential to any collaborative application in immersive virtual environments [52]. One could experience a sense of co-presence when facing social actors such as virtual characters controlled by other persons (avatars) or autonomous virtual agents [53]. In the frame of our experiment, we focus especially on two dimensions of the sense of social presence identified by Harms and Biocca [54] as they appeared to be particularly relevant regarding the tasks of our experiment: co-presence and perceived message understanding. First, the sense of co-presence is defined as the belief of not being alone and the degree of mutual awareness. It requires users to be collocated in a shared space. Second, the perceived message understanding dimension refers to two different aspects of communication. It concerns users' ability to understand the messages being received from their interactant. It also refers to their perception of their interactant's level of message understanding.

It has been demonstrated that visually representing a communication partner in virtual environments makes it possible to locate him and thus to induce a sense of social presence [55, 56]. While previous experiments studied the impact of visual realism on the sense of co-presence in collaborative virtual environments [51, 57, 6], it should be noted that these experiments were carried out almost twenty years ago and that there is a graphic gap and some technological limitations which should be taken into account. Garau *et al.* [6] demonstrated that humanoid avatars with a high level of visual fidelity and realistic gaze induce a higher sense of social presence than avatars with a random gaze system. This experiment also highlights the fact that the higher the visual fidelity, the higher the requirements for realistic behavior. Similarly, Bente *et al.* [58] found that participants felt higher levels of co-presence when their communication partners maintained longer mutual eye contact using simulated gaze data. In terms of anthropomorphism, it has been demonstrated that users seem to be less prone to accept virtual characters' flaw as they get closer to realistic human appearance [57, 9, 37]. Back in 2003, the experiment of Nowak and Biocca [57] revealed that participants felt a higher level of co-presence when interacting with an avatar presenting a lower anthropomorphism level than the one with the highest visual fidelity. However, authors underline that the most realistic condition was based on floating heads without a body which could induce revulsion responses from some participants who reported feeling strange about interacting with such virtual characters. This statement is in contrast with the work of Herrera *et al.* [59], Heidicker *et al.* [60] and Greenwald *et al.* [61] who observed high levels of co-presence with partial avatars (floating head and hands) and sometimes even higher than with full-body characters presenting low tracking fidelity [59, 60]. It appears that a partial virtual body could be better than a technically limited full-body representation. To investigate further the impact of avatar anthropomorphism we ran two experiments using avatars with different facial properties.

3. Avatars and Apparatus

3.1. Avatars

We designed three avatars (Figures 1, 2) used in both the asymmetric collaborative task (AC) of the first experiment and in the negotiation task (N) of the second experiment to investigate the impact of facial anthropomorphism on body ownership, attractiveness, social presence and collaboration in immersive virtual environments. Each pair of participants embodies one of the three avatar conditions classified according to their facial properties:

- Robot 1 (R1): virtual eyes and mouth. The screen-based face displays a set of textures to animate both the eyes and the mouth. The robot's mouth is animated when the user is speaking using a sequence of six textures.

- Robot 2 (R2): physical eyes and virtual mouth. The virtual mouth is an equalizer displaying bars matching the intensity of the user's vocal frequencies.
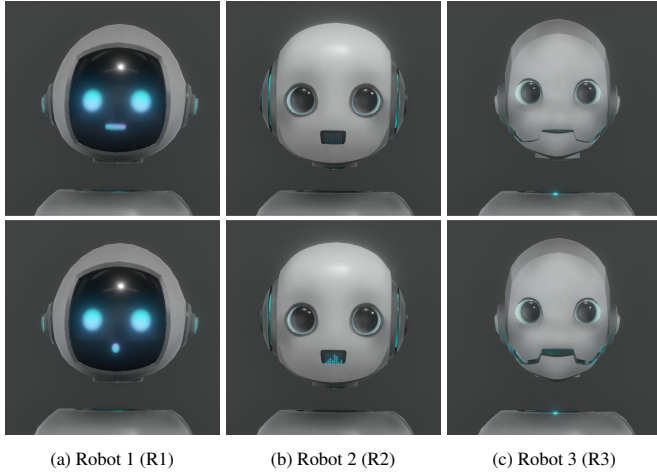

(a) Robot 1 (R1) (b) Robot 2 (R2) (c) Robot 3 (R3)

Figure 2: Screenshots of the three avatar conditions of the experiment with inactive (top) and active mouths (bottom).

(a) Room 1 (b) Room 2

Figure 3: Participants equipped with the HTC Vive pro virtual reality headset.

- Robot 3 (R3): physical eyes and mouth. The physical jaw moves according to the user's voice intensity.

It should be noted that in these experiments the different facial properties require different gaze implementations due to the nature of the eyes (texture versus mesh) to achieve a convincing gaze behavior. While we use a set of textures to animate the eyes of the first robot (R1), both the second (R2) and the third robot (R3) benefit from a model that aligns the eyes in a plausible way depending on the movement of the participants. The resulting behavior can be observed in the video provided as supplementary material.

3.2. Apparatus

Two HTC Vive pro are used for both experiments to display the virtual environment at a refresh rate of 90 Hz with a resolution of 2880 x 1600 pixels (1440 x 1600 pixels per eye) and a field of view of 110 degrees (Figure 3). We used the six degrees of freedom of the headset and of the controllers to track the participants and to animate their avatars. The triggers of the controllers were used to grab and interact with the objects of the experiments. Computers are composed of an Intel Xeon E5-1607 @ 3.10 GHz processor and a Nvidia GeForce GTX 1080 graphics card.

4. Experiment 1: Asymmetric Collaboration

In the first experiment each pair of participants embodies one of the three characters presented in Section 3 (same avatar for each pair of participants (Figure 2)) in a between-subject design. They have to collaborate to solve two puzzle games (Figure 4). Each participant has the plan corresponding to his/her partner's puzzle. It creates an asymmetric collaborative situation where they have to explain alternately where to place the 3D parts on the game boards. At the end of the experiment the participants evaluate the attractiveness of the avatar, their sense of body ownership and their sense of social presence. These data are then compared with their performance to achieve the collaborative task.

4.1. VR application

The virtual reality application used for the experiment was developed using the real-time 3D engine Unity. The environment consists in a room matching the avatars' appearance and textures to create a coherent and plausible environment. Both avatars appear in the center of the room on each side of the table where the game boards are located. Participants are able to communicate using both verbal and non-verbal communication, but they cannot see their partner's plan required to complete their own puzzle.

4.2. Participants

36 participants (10 females and 26 males) aged from 21 to 47 ($M = 23.42$, $SD = 4.34$) were recruited for the experiment. Each subject has a correct or corrected vision. All the participants had prior experience with immersive virtual reality and
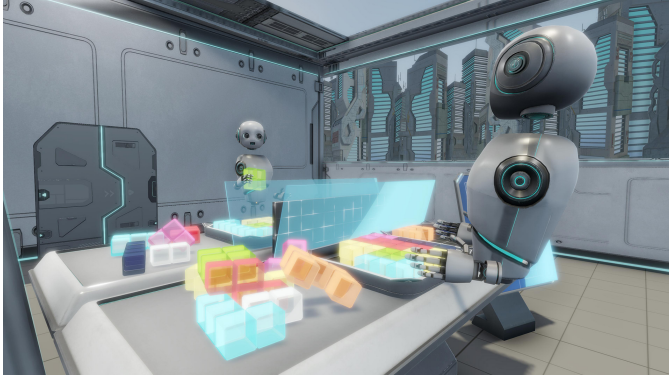
4

Figure 4: Participants performing the collaborative task.

29 of them play video games at least 2 hours a week. 22 out of 29 are used to playing multiplayer online games. We recruited experienced participants as we believe our results will be more relevant for future use cases considering the fact that in a near future most people will have such an experience with virtual reality. Indeed, participants experiencing VR for the first time may be distracted by the novelty and might be less focused on the task and their partner, which could have an impact on the results in terms of both performance and subjective measures.

4.3. Procedure and Measures

Prior to the experiment each participant read and signed a consent form. Participants were informed that they were free to withdraw from the experiment at any time without giving reasons. Then, they filled the pre-experiment questionnaire to collect their demographic information as well as relevant data regarding the content of the experiment such as any previous experience with virtual reality and video games.

Each pair of participants was provided with the necessary instructions to begin the experiment and was equipped with the virtual reality headset in a separated room. As soon as the participants were geared up, they were immersed in the virtual environment. The experiment began in two distinct virtual rooms where they embodied their avatar for two minutes in front of a virtual mirror. Then, they met each other in another environment dedicated to the collaborative task. Each participant had to complete two puzzles on his/her table. As a training phase they completed the first puzzle independently as they had the plan and the parts on their own virtual table. As soon as both participants completed their first puzzle, they had to collaborate to complete the second one following the instructions of their partner who had the corresponding plan on his/her side.

At the end of the experiment participants completed the questionnaire to assess the sense of body ownership, the sense of social presence (co-presence and perceived message understanding dimensions of the Networked Mind Social Presence Measure [54]) and the attractiveness of their avatar [7] using seven-point semantic scales (Table 1). Objective performance data were collected via the application in a CSV (Comma-Separated Values) file. This file contains the completion duration (CD) of the task as well as the speaking duration (SD) of each participant.

Table 1: Body ownership and attractiveness questionnaire. Items range from 1 to 7.

Body ownership
I felt that the virtual body that I saw when I looked down was my body.
I felt that the virtual body I saw in the mirror was my body.
I felt that the virtual body was not me.*
Attractiveness
To what extent your avatar seemed attractive to you?
Social Presence (Co-presence)
I noticed my partner.
My partner noticed me.
My partner's presence was obvious to me.
My presence was obvious to my partner.
My partner caught my attention.
I caught my partner's attention.
Social Presence (Perceived Message Understanding)
My thoughts were clear to my partner.
My partner's thoughts were clear to me.
It was easy to understand (my partner).
My partner found it easy to understand me.
Understanding my partner was difficult.*
My partner had difficulty understanding me.*

* reverse scored item.

4.4. Hypotheses

Based on previous work reported in our literature review and to the proposed experimental design, here is a list of hypotheses relative to the impact of facial anthropomorphism on attractiveness, body ownership, social presence and performance in collaborative tasks:

- H1: Avatars presenting a high level of facial anthropomorphism improve users' sense of body ownership in immersive collaborative virtual environments.

- H2: Avatars with more anthropomorphic facial properties are more appealing to users in immersive collaborative virtual environments.

- H3: Avatars presenting a high level of facial anthropomorphism improve users' sense of social presence in immersive collaborative virtual environments.

- H4: Avatars presenting a high level of facial anthropomorphism enable better communication and performance in collaborative tasks in immersive virtual environments.

4.5. Results

Data were tested for normality and homogeneity of variance. The Shapiro-Wilk Test revealed that most of the variables were not normally distributed and Levene Test showed that the variances for body ownership, attractiveness and objective performance were not equal ($p < 0.05$). As our data violate parametric tests' assumptions, we used alternative non-parametric tests except for social presence. Results are considered significant when $p < 0.05$ (Table 2). Bonferroni's correction was applied to adjust alpha value for post-hoc pairwise comparisons resulting in a significance level set at $p < 0.017$.

4.5.1. Body Ownership

A Kruskal-Wallis Test revealed no significant difference in ownership scores between the three avatar conditions (Figure 5a) ($p > 0.05$). Thus we cannot state that the facial anthropomorphism level of the three avatars proposed in this experiment impact users' sense of body ownership leading to reject our first hypothesis (H1).

4.5.2. Attractiveness

A Kruskal-Wallis Test revealed a statistically significant difference in avatars' attractiveness scores between the three avatar conditions (1 $N = 12$: R1, 2 $N = 12$: R2, 3 $N = 12$: R3), χ^2 (2, $N = 36$) = 11.61, $p = 0.003$ (Figure 5b). The R2 group recorded the higher median score ($Md = 6.00$), while the R3 group recorded a value of 5.50 and the R1 group a value of 4.00. A Mann-Whitney U Test revealed a significant difference in the attractiveness scores of R1 ($Md = 4.00$, $N = 12$) and R2 ($Md = 6.00$, $N = 12$), $U = 27$, $Z = -2.69$, $p = 0.008$. Another significant difference was observed in the attractiveness scores of R1 ($Md = 4.00$, $N = 12$) and R3 ($Md = 5.50$, $N = 12$), $U = 27$, $Z = -3.15$, $p = 0.002$. Although we observed no significant difference between the Robot 2 and the Robot 3 conditions, our second hypothesis (H2) seems valid.

4.5.3. Social presence

A one-way between-groups analysis of variance was conducted to explore the impact of avatar's facial anthropomorphism on sense of co-presence and perceived message understanding. There was no statistically significant difference at the $p < .05$ level in co-presence score for the three conditions: F (2, 33) = 2.4, $p = 0.10$. Concerning perceived message understanding score, there was no statistically significant difference either: F (2, 33) = 1.5, $p = 0.24$. These results do not confirm our third hypothesis (H3) and led us to develop a second experiment to
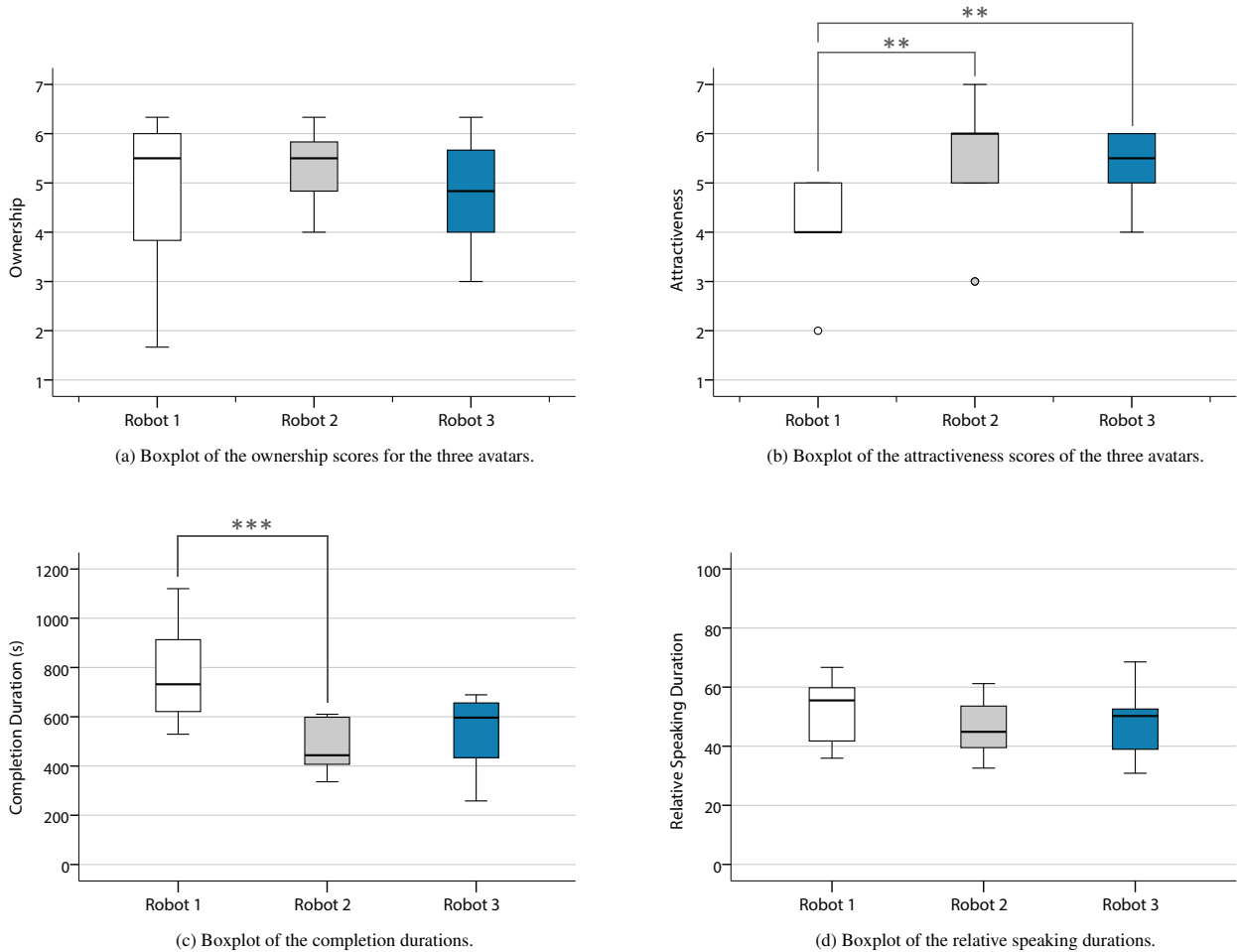

(a) Boxplot of the ownership scores for the three avatars.

(b) Boxplot of the attractiveness scores of the three avatars.

(c) Boxplot of the completion durations.

(d) Boxplot of the relative speaking durations.

Figure 5: Boxplots of the results of the asymmetric collaborative experiment. * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

investigate further the potential effect of the task carried out by the participants on their sense of social presence.

4.5.4. Completion and Speaking Durations

A Kruskal-Wallis Test revealed a statistically significant difference in the completion duration depending on the controlled avatar (1 N = 12: R1, 2 N = 12: R2, 3 N = 12: R3), χ^2 (2, N = 36) = 13.33, p = 0.001 (Figure 5c). The R2 group recorded the lower median duration (Md = 443.50 s), while the R1 group recorded a duration of 732.00 s and the R3 group a duration of 596.50 s. A Mann-Whitney U Test revealed a significant difference in the completion duration between R1 (Md = 732.00 s, N = 12) and R2 (Md = 443.50 s, N = 12), U = 8, Z = -3.71, p < 0.001. A trend can be observed in the completion duration between the R1 (Md = 732.00 s, N = 12) and R3 (Md = 596.50 s, N = 12), U = 40, Z = -1.86, p = 0.064.

The speaking duration being obviously linked to the completion duration, we first calculated a relative speaking duration (score between 0 and 100, where 0 means that the participants did not speak and 100 that they spoke for the entire duration of the experiment). A Kruskal-Wallis Test revealed no significant difference in the relative speaking duration between the three avatar conditions (p > 0.05).

According to the completion duration of the experiment, it seems that the facial anthropomorphism level of the three avatar conditions can impact users' performance, especially when comparing the avatar presenting the lower anthropomorphism level (R1) to the others (R2 and R3) which is consistent with our fourth hypothesis (H4). However, it does not impact the duration of their verbal communication.

4.5.5. Correlations

Using Spearman correlations (Table 3), we unexpectedly observed a strong negative correlation between avatar attractiveness and completion duration, rho = -0.564, n = 36, p < 0.001. The more attractive the avatar, the shorter the completion duration. However, the collected data are not sufficient to explain such results and no mediation analysis can be carried out to test if attractiveness could act as a mediator between anthropomorphism and performance as normality and homogeneity of variance assumptions are not met.

4.6. Discussion

We observed several significant differences between the three facial anthropomorphism conditions (R1: virtual eyes and mouth, R2: physical eyes and virtual mouth, R3: physical eyes and mouth), especially concerning attractiveness (H2) and users' performance regarding the task completion (H4). However, we observed no statistically significant difference concerning the sense of ownership and the sense of social presence. Therefore, we cannot validate our first (H1) and third (H3) hypotheses.

Table 2: Statistical summary of the answers to the post experiment questionnaire (Ownership (O), Attractiveness (Att), Co-presence (CP) and Perceived Message Understanding (PMU)) and of the objective data (Completion Duration (CD) and Relative Speaking Duration (RSD)).

	Robot 1 (R1)		Robot 2 (R2)		Robot 3 (R3)		
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	p
O	4.81	1.59	5.31	0.72	4.78	1.07	0.558
Att	4.25	0.87	5.42	1.24	5.42	0.45	0.003*
CP	5.64	1.03	6.41	0.60	5.96	0.92	0.104
PMU	5.01	0.71	5.44	0.71	5.57	1.03	0.242
CD	774.50	213.47	473.00	105.98	538.33	156.61	0.001*
RSD	52.29	10.90	46.25	9.09	47.69	11.00	0.392

*Mean and standard deviation are provided for each condition (R1, R2 and R3). * indicates significant differences.*

Table 3: Spearman correlation between Ownership (O), Attractiveness (Att), Co-presence (CP), Perceived Message Understanding (PMU), Completion Duration (CD) and Relative Speaking Duration (RSD).

	O	Att	CP	PMU	CD	RSD
Ownership (O)	-	0.129	0.311	0.102	-0.012	0.123
Attractiveness (Att)		-	-0.037	0.02	-0.564**	-0.07
Co-presence (CP)			-	0.523**	-0.227	-0.163
Perceived Message Understanding (PMU)				-	-0.251	-0.012
Completion Duration (CD)					-	0.094
Relative Speaking Duration (RSD)						-

* p < 0.05 (2-tailed), ** p < 0.01 (2-tailed)

The sense of ownership is high for each avatar, which means that participants were able to embody every robot independently of their facial properties. We expected high ownership scores for every condition thanks to visuomotor synchrony acting as a critical bottom-up contributor [2]. Nevertheless, we also expected potential significant differences with higher sense of ownership for avatars presenting higher anthropomorphism levels as human-like similarities could increase the sense of embodiment [25, 20]. However, it seems that the differences between our facial anthropomorphism conditions, only limited to facial properties (same virtual body and hands), are too slight to affect the sense of ownership. Indeed, participants cannot see their own avatar's face as soon as they join the collaborative room (no virtual mirror anymore).

Our results demonstrate that attractiveness levels are significantly higher for both the second condition (R2) and the third condition (R3) compared to the first one (R1). Participants tend to prefer avatars with more anthropomorphic facial properties, which demonstrates the validity of our second hypothesis (H2). Back to the three criteria of visual fidelity (see section 2.2) [5], previous experiments demonstrated that realism is not a good predictor of attractiveness [62, 7, 37], but that truthfulness can improve attractiveness evaluations of virtual characters [9]. Based on our results, it seems that facial anthropomorphism can also positively impact of virtual characters' attractiveness evaluations, at least concerning their facial properties (eye gaze and mouth type). However, it should be noted that these results are observed for non-realistic avatars and that virtual humans could lead to different outcomes. Moreover, attractiveness evaluations are subjective and, despite the fact that the facial properties of the avatars are actually different, artistic design can also impact subjective evaluations of attractiveness.

We observed no significant difference in terms of social presence between the three avatars and we assume that it may be due to the type of task carried out by the participants. In this asymmetric collaborative task they tend to focus most of the time on the game board relying on verbal communication to follow their partner's instructions. This observation led us to develop a second experiment focusing on social presence introduced in the next section of this paper.

Objective data revealed that participants performed significantly better using the second condition compared to the first one with shorter completion duration. We also observed a trend between the first and the third conditions, the third one allowing for better performance. Overall participants tend to perform better in collaborative tasks using more anthropomorphic avatars. However, the statistical analysis revealed no significant difference when comparing the relative speaking duration. We argue that more anthropomorphic appearance could favor communication in virtual environments leading to an increased performance in collaborative tasks. Unexpectedly, we observed a correlation between attractiveness and performance. This result cannot be explained based on the data we collected and only rises new hypotheses. It is possible that attractiveness led participants to look at each other and to focus on their partner's avatar favoring non-verbal communication and improving their performance. Further studies must be conducted using gaze tracking technologies to analyse if attractiveness increases the time participants spend looking at each other in order to investigate if avatar attractiveness could be a way to improve collaboration in immersive virtual environments.

5. Experiment 2: Negotiation

The results of the first experiment revealed no significant difference regarding the impact of facial properties on the sense of social presence. We suspected that the asymmetric collaboration task where participants must focus on the game board while listening to their partners' instructions could potentially explain why the facial anthropomorphism level of the avatars did not affect the results. Based on previous work and on the results of this first experiment, we suspected that social presence could be affected by the proposed task [43, 63]. Indeed, Garau *et al.* [6] mention that their results in terms of social presence could have been influenced by the negotiation task in which participants were involved. Therefore, we designed another task while keeping the same avatars to compare two different collaborative situations following a between-subject design. The second task presents a negotiation situation where participants face each other and must discuss in order to reach an agreement (Figure 6). We developed an adapted version of the NASA's survival on the moon exercise. Partners must collaborate to sort objects from 1 to 15 in order to survive after forced landing on the moon's surface. They could freely reconsider their choices as long as the experiment is not finished. We designed an interface composed of 15 icons (one for each object) ensuring that participants face each other during the whole experience. They can drag and drop the icons on a dedicated table to sort the objects.

5.1. Participants

We used the same inclusion criteria for the second experiment and we hired 36 participants (11 females and 25 males) aged from 19 to 30 ($M = 23.03$, $SD = 1.98$) who had prior experience with immersive virtual reality.
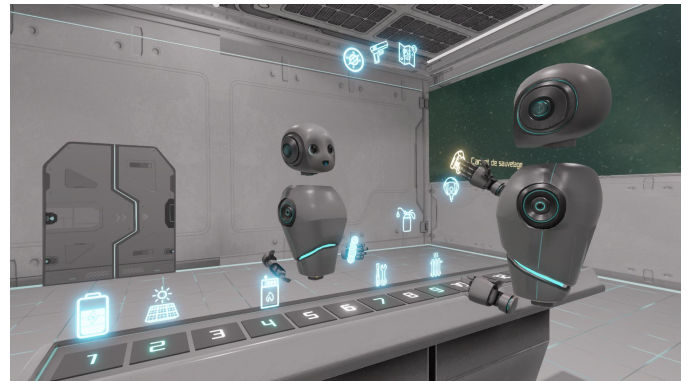

Figure 6: Participants performing the negotiation task.

5.2. Procedure and Measures

The procedure of this second experiment was similar to the previous one. Participants signed a consent form and they were informed that they were free to withdraw from the experiment at any time without giving reasons. They filled the pre-experiment questionnaire to collect their demographic information as well as their previous experience with virtual reality and video games.

Participants were provided with the instructions to begin the experiment and were equipped with the virtual reality headset (Figure 3). Similarly to the asymmetric collaboration task, the negotiation task begins in two distinct virtual rooms where participants embody their avatar for two minutes in front of a virtual mirror. Then, participants meet each other in another room to carry out the negotiation task. At the end of the experiment participants complete the questionnaire to assess the co-presence and the perceived message understanding dimensions of social presence using seven-point semantic scales.

5.3. Hypotheses

Considering the results of our first experiment we adapted our previous hypothesis (H3 of the first experiment) and we added a new hypothesis concerning the potential impact of the task type:

- H1: Avatars presenting a high level of facial anthropomorphism improve users' sense of social presence in collaborative tasks involving face-to-face interactions in immersive virtual environments.

- H2: Collaborative tasks involving face-to-face interaction and favoring non-verbal communication in immersive virtual environments induce a higher sense of social presence compared to collaborative tasks that require less visual contact.

5.4. Results

Data were tested for normality and homogeneity of variance. The Shapiro-Wilk Test revealed that some variables were not normally distributed ($p < 0.05$). However, considering that the Levene Test showed that the variances were not significantly different we used parametric tests to analyze the data. Results are considered significant when $p < 0.05$.

A two-way between-groups analysis of variance was conducted to explore the impact of facial anthropomorphism and of the type of task on the co-presence dimension of social presence (Table 4, Figure 7a, Figure 7b). Participants were divided into six groups according to the robot they controlled (R1, R2 and R3) and the type of task they carried out: asymmetric collaboration (based on the data collected in the first study) and negotiation. The interaction effect between anthropomorphism and task was not statistically significant, $F(2, 66) = 3.03$, $p = 0.055$. There was a statistically significant main effect of task type, $F(1, 66) = 4.55$, $p = 0.037$. The effect size was medium (partial eta squared = 0.065). The mean co-presence score for the negotiation task ($M = 6.41$, $SD = 0.72$) was superior to the asymmetric collaboration task ($M = 6$, $SD = 0.90$). The main effect for anthropomorphism, $F(2, 66) = 0.47$, $p = 0.63$, did not reach statistical significance.

Another two-way between-groups analysis of variance was conducted to explore the effect of facial anthropomorphism and of the type of task on the perceived message understanding dimension of social presence. The interaction effect between anthropomorphism and task was not statistically significant, $F(2, 66) = 1.22$, $p = 0.302$. There was a statistically significant main effect of task type, $F(1, 66) = 29.96$, $p < 0.001$. The effect size was large (partial eta squared = 0.312). The mean perceived message understanding score for the negotiation task ($M = 6.32$, $SD = 0.67$) was superior to the asymmetric collaboration task ($M = 5.34$, $SD = 0.84$). The main effect for anthropomorphism, $F(2, 66) = 0.66$, $p = 0.519$, did not reach statistical significance.

We observed no significant difference concerning the impact
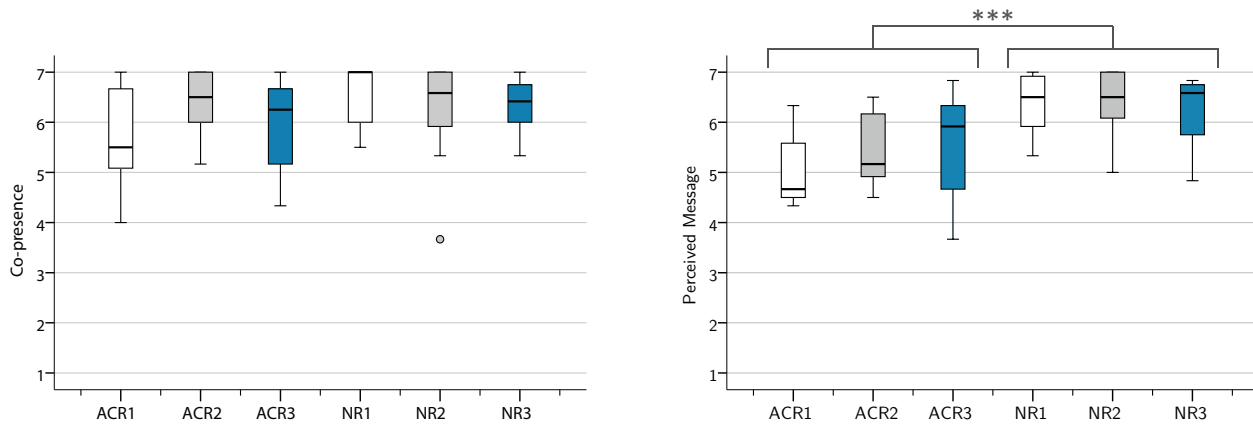
(a) Boxplot of the co-presence scores for each avatar condition (R1, R2, R3) during both the asymmetric collaborative (AC) and the negotiation (N) tasks.

(b) Boxplot of the perceived message understanding scores for each avatar condition (R1, R2, R3) during both the asymmetric collaborative (AC) and the negotiation tasks (N).

Figure 7: Boxplots of the social presence scores. * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 4: Statistical summary of the answers to the post experiment questionnaire (Co-presence (CP) and Perceived Message Understanding (PMU)).

	Asym. collaboration (AC)		Negotiation (N)	
	$\bar{x}$	σ	$\bar{x}$	σ
CP Robot 1	5.64	1.03	6.61	0.59
CP Robot 2	6.41	0.60	6.25	0.99
CP Robot 3	5.96	0.92	6.36	0.49
PMU Robot 1	5.01	0.71	6.36	0.59
PMU Robot 2	5.44	0.71	6.38	0.74
PMU Robot 3	5.57	1.03	6.24	0.72

Mean and standard deviation are provided for each condition (AC and N).

of avatar facial anthropomorphism on social presence, which invalidates our first hypothesis (H1). However, it appears that the type of task carried out impacts both the co-presence and the perceived message understanding dimensions of social presence. Higher scores were observed for the negotiation task. Our second hypothesis seems valid and will be discussed further in the next section.

5.5. Discussion

The results revealed no significant difference concerning the impact of facial anthropomorphism on participants' sense of social presence. Based on the subjective data collected thanks to the post-experiment questionnaire after both tasks (asymmetric collaboration and negotiation), and in the absence of an interaction effect between avatar anthropomorphism and the type of task carried out, our first hypothesis (H1) cannot be confirmed. Previous research demonstrated that users can feel a high sense of co-presence using partial avatars (floating head and hands) [60, 61]. It is therefore not surprising that we observed a very high sense of co-presence with the three conditions. However, we expected some differences with a potential improvement as the facial properties of the avatars get closer to human appearance. We argue that it could be linked to a potential ceiling effect. Participants reported a very high sense of co-presence and a clear understanding of their partner messages with every avatar condition. These results could be explained by the fact that the effect of facial properties can be minor compared to the impact of verbal and non-verbal communication (body language, hand movements, etc.). As observed in previous experiments [57, 37], it is also possible that users are more sensitive to realistic facial properties of virtual humans and that such differences do not matter so much on robotic characters. Participants seem to be more prone to accept a wide range of facial properties on non-human avatars as they avoid falling in the Uncanny Valley [38, 39]. Despite the fact that we cannot confirm our hypothesis, our results seem to indicate that it is possible to induce a high sense of social presence in immersive virtual environments using non-human virtual characters.

As stated in the related work section we identified very few experiments aiming at investigating the impact of the task type

on the sense of social presence, especially when it comes to immersive virtual environments [43, 63]. Our results demonstrate that social presence is context-sensitive. We observed significant differences when comparing the results of the two tasks in terms co-presence and perceived message understanding, which corroborates our second hypothesis concerning the impact of the task type on users' sense of social presence. A difference between the two tasks was observed in favor of the negotiation task in terms of co-presence. It should be noted that the median scores of the co-presence dimension are very high in both tasks regardless of the avatar condition (> 5 on seven point scales). We also observed several significant differences concerning the perceived message understanding dimension. According to Harms and Biocca [54] this dimension refers to the ability of the participants to understand the messages being received from their partner as well as their perception of the partner's level of message understanding. It appeared that the participants were more able to understand their partners in the negotiation task. There are multiple ways to explain such results. First, one can argue that the asymmetric task could be more difficult to explain when it comes to providing your partner with the instructions required to place the 3D parts on the game board. It is possible that some participants misunderstood each other leading to lower scores in the perceived message. Another explanation could be that visual contact between the participants favored non-verbal communication, especially during the negotiation task which was designed to ensure that the participants face each other for most of the immersion period in the virtual environment. Both verbal and non-verbal communication could have led to a flawless interaction between the participants, which would have improved their overall sense of social presence.

6. Limitations and Future Work

Our results provide some guidelines to design avatars for immersive collaborative virtual environments using consumer grade VR devices. Nevertheless, it should be noted that the analysis is based on a relatively small sample of 72 participants considering both experiments. Other studies must be conducted to investigate the impact of avatar anthropomorphism in collaborative virtual environments. In addition, such studies could benefit from pilot tests to rank the perceived anthropomorphism level of the avatars to further validate the design of the experimental conditions. Even if it was a design choice to match most VR applications available to the general public not relying on realistic virtual humans, this experiment focuses on facial properties of robotic characters that do not allow for expressiveness similar to that of organic models using blend shapes. Several other morphological factors potentially affecting non-verbal communication and interactions such as gestures and animations are not considered in this study. Indeed, the three avatars provide the participants with the same chest as well as the same virtual hands. We encourage developers to design avatars with regards to the proposed tasks as affordance and interaction metaphors can also impact the way users collaborate.

Regarding post-experiment measures, participants were asked to rate the attractiveness of their own avatar which was only seen in a mirror for two minutes at the beginning of the experiment. However, each pair of participants controlled an identical avatar and it is possible that they considered their partner's avatar in their evaluations. In this context, it should be noted that the level of control over characters' animation can impact attractiveness evaluations [62]. Furthermore, as stated in the results section of the second experiment, a potential ceiling effect can be observed regarding the co-presence dimension. We suppose that verbal communication is more important than the impact of facial properties when it comes to social presence. It could be interesting to investigate which factors of non-verbal communication are significant in an experiment where no verbal communication is allowed. Such a study could provide the community with additional guidelines on factors to consider when designing avatars for collaborative applications.

7. Conclusion

We designed two experiments in immersive virtual environments to investigate if the sense of body ownership, avatar attractiveness, social presence and performance in collaborative tasks are impacted by facial properties of virtual characters and whether or not these results are task sensitive. We observed a very high sense of ownership for each condition with no significant difference leading to the conclusion that the different facial anthropomorphism levels of the three robotic avatars are too slight to affect ownership compared to bottom-up factors such as visuomotor synchrony. However, the results revealed several significant differences concerning attractiveness and performance as well as a correlation between these two notions. Firstly, more anthropomorphic facial properties appear to improve attractiveness. Secondly, participants performed better with avatars having more anthropomorphic facial properties in the asymmetric collaborative task of the first experiment consisting in solving a puzzle game alternately according to their partners' instructions. We unexpectedly observed a correlation between attractiveness and performance with high level of attractiveness associated with better performance. We hypothesize that higher attractiveness could lead users to focus more on the avatar of their partner, which in turn leads to an improved non-verbal communication and therefore to better collaborative performance. Further experiments must be conducted using gaze tracking data to validate this new hypothesis.

We observed no significant difference in terms of social presence in the asymmetric collaborative task of the first experiment, which led us to conduct a second experiment using the same avatars in a negotiation task to ensure that participants face each other while they interact together. The negotiation task required the participants to classify objects and to reach an agreement. We did not observe significant differences concerning the impact of facial properties on the two dimensions of social presence we considered in this experiment: co-presence and perceived message understanding. We argue that the effect of facial properties can be irrelevant compared to the impact of both verbal communication and non-verbal communication.

It is also possible that users could be more sensitive to facial properties when they embody realistic virtual humans. However, we demonstrated that social presence is impacted by the type of collaborative task carried out. Our results revealed that the negotiation task induced a higher sense of social presence compared to the asymmetric collaborative task. We assume that face-to-face interactions favor non-verbal behaviors leading to an improved overall communication in immersive collaborative virtual environments.

Acknowledgments

References

[1] D. Roth, K. Waldow, F. Stetter, G. Bente, M. E. Latoschik, A. Fuhrmann, Siamc: A socially immersive avatar mediated communication platform, in: Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology, VRST '16, Association for Computing Machinery, New York, NY, USA, 2016, p. 357–358. doi:10.1145/2993369.2996302. URL https://doi.org/10.1145/2993369.2996302

[2] E. Kokkinara, M. Slater, Measuring the effects through time of the influence of visuomotor and visuotactile synchronous stimulation on a virtual body ownership illusion, Perception 43 (1) (2014) 43–58. doi:https://doi.org/10.1068/p7545

[3] W. Steptoe, R. Wolff, A. Murgia, E. Guimaraes, J. Rae, P. Sharkey, D. Roberts, A. Steed, Eye-tracking for avatar eye-gaze and interactional analysis in immersive collaborative virtual environments, in: Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work, CSCW '08, Association for Computing Machinery, New York, NY, USA, 2008, p. 197–200. doi:10.1145/1460563.1460593. URL https://doi.org/10.1145/1460563.1460593

[4] W. Steptoe, O. Oyekoya, A. Murgia, R. Wolff, J. Rae, E. Gumaraes, D. Roberts, A. Steed, Eye tracking for avatar eye gaze control during object-focused multiparty interaction in immersive collaborative virtual environments, in: 2009 IEEE Virtual Reality Conference, 2009, pp. 83–90. doi:10.1109/VR.2009.4811003.

[5] M. Garau, The Impact of Avatar Fidelity on Social Interaction in Virtual Environments, Ph.D. thesis, University College London (2003).

[6] M. Garau, M. Slater, V. Vinayagamoorthy, A. Brogni, A. Steed, M. A. Sasse, The Impact of Avatar Realism and Eye Gaze Control on Perceived Quality of Communication in a Shared Immersive Virtual Environment, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '03, ACM, New York, NY, USA, 2003, pp. 529–536. doi:10.1145/642611.642703. URL http://doi.acm.org/10.1145/642611.642703

[7] E. Zell, C. Aliaga, A. Jarabo, K. Zibrek, D. Gutierrez, R. McDonnell, M. Botsch, To stylize or not to stylize?: The effect of shape and material stylization on the perception of computer-generated faces, ACM Trans. Graph. 34 (6) (2015) 184:1–184:12. doi:10.1145/2816795.2818126. URL http://doi.acm.org/10.1145/2816795.2818126

[8] R. Fleming, B. J. Mohler, J. Romero, M. J. Black, M. Breidt, Appealing avatars from 3d body scans: Perceptual effects of stylization, in: J. Braz, N. Magnenat-Thalmann, P. Richard, L. Linsen, A. Telea, S. Battiato, F. Imai (Eds.), Computer Vision, Imaging and Computer Graphics Theory and Applications, Springer International Publishing, Cham, 2017, pp. 175–196.

[9] G. Gorisse, O. Christmann, S. Houzangbe, S. Richir, From robot to virtual doppelganger: Impact of avatar visual fidelity and self-esteem on perceived attractiveness, in: Proceedings of the 2018 International Conference on Advanced Visual Interfaces, AVI '18, ACM, New York, NY, USA, 2018, pp. 48:1–48:5. doi:10.1145/3206505.3206525. URL http://doi.acm.org/10.1145/3206505.3206525

11

[10] M. Slater, D. P. Marcos, H. Ehrsson, M. V. Sanchez-Vives, Inducing illusory ownership of a virtual body, Frontiers in neuroscience 3 (2009) 214–220.

[11] R. Schroeder, Being there together and the future of connected presence, Presence: Teleoperators and Virtual Environments 15 (4) (2006) 438–454. doi:10.1162/pres.15.4.438.

[12] F. Biocca, C. Harms, J. K. Burgoon, Toward a more robust theory and measure of social presence: Review and suggested criteria, Presence: Teleoperators & virtual environments 12 (5) (2003) 456–480. doi:https://doi.org/10.1162/105474603322761270.

[13] K. Kilteni, R. Groten, M. Slater, The sense of embodiment in virtual reality, Presence: Teleoperators and Virtual Environments 21 (4) (2012) 373–387.

[14] B. Lenggenhager, T. Tadi, T. Metzinger, O. Blanke, Video Ergo Sum: Manipulating Bodily Self-Consciousness, Science 317 (5841) (2007) 1096–1099.
URL http://science.sciencemag.org/content/317/5841/1096

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

[16] G. Gorisse, O. Christmann, E. A. Amato, S. Richir, First- and Third-Person Perspectives in Immersive Virtual Environments: Presence and Performance Analysis of Embodied Users, Frontiers in Robotics and AI 4 (2017) 33.
URL http://journal.frontiersin.org/article/10.3389/frobt.2017.00033

[17] H. G. Debarba, E. Molla, B. Herbelin, R. Boulic, Characterizing embodied interaction in First and Third Person Perspective viewpoints, in: 2015 IEEE Symposium on 3D User Interfaces (3DUI), Arles, 2015, pp. 67–72.

[18] M. Slater, B. Spanlang, M. V. Sanchez-Vives, O. Blanke, First person experience of body transfer in virtual reality, PloS one 5 (5) (2010) 1–9. doi:10.1371/journal.pone.0010564.

[19] O. Blanke, T. Metzinger, Full-body illusions and minimal phenomenal selfhood, Trends in cognitive sciences 13 (1) (2009) 7–13.

[20] G. Gorisse, O. Christmann, S. Houzangbe, S. Richir, From Robot to Virtual Doppelganger: Impact of Visual Fidelity of Avatars Controlled in Third-Person Perspective on Embodiment and Behavior in Immersive Virtual Environments, Frontiers in Robotics and AI 6 (2019) 8. doi:10.3389/frobt.2019.00008.
URL https://www.frontiersin.org/article/10.3389/frobt.2019.00008

[21] C. Jeunet, L. Albert, F. Argelaguet, A. Lécuyer, "do you feel in control?": Towards novel approaches to characterise, manipulate and measure the sense of agency in virtual environments, IEEE Transactions on Visualization and Computer Graphics 24 (4) (2018) 1486–1495. doi:10.1109/TVCG.2018.2794598.

[22] E. A. Caspar, A. Cleeremans, P. Haggard, The relationship between human agency and embodiment, Consciousness and cognition 33 (2015) 226–236.

[23] D. Dewez, R. Fribourg, F. Argelaguet, L. Hoyet, D. Mestre, M. Slater, A. Lécuyer, Influence of personality traits and body awareness on the sense of embodiment in virtual reality, in: 2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2019, pp. 123–134. doi:10.1109/ISMAR.2019.00-12.

[24] S. Bovet, H. G. Debarba, B. Herbelin, E. Molla, R. Boulic, The critical role of self-contact for embodiment in virtual reality, IEEE Transactions on Visualization and Computer Graphics 24 (4) (2018) 1428–1436. doi:10.1109/TVCG.2018.2794658.

[25] T. Waltemate, D. Gall, D. Roth, M. Botsch, M. E. Latoschik, The impact of avatar personalization and immersion on virtual body ownership, presence, and emotional response, IEEE transactions on visualization and computer graphics 24 (4) (2018) 1643–1652.

[26] M. E. Latoschik, D. Roth, D. Gall, J. Achenbach, T. Waltemate, M. Botsch, The effect of avatar realism in immersive social virtual realities, in: Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology, VRST '17, ACM, New York, NY, USA, 2017, pp. 39:1–39:10. doi:10.1145/3139131.3139156.
URL http://doi.acm.org/10.1145/3139131.3139156

[27] F. Argelaguet, L. Hoyet, M. Trico, A. Lecuyer, The role of interaction in virtual embodiment: Effects of the virtual hand representation, in: 2016 IEEE Virtual Reality (VR), Greenville, SC, 2016, pp. 3–10.

[28] M. Botvinick, J. Cohen, Rubber hands' feel 'touch that eyes see, Nature 391 (6669) (1998) 756.

[29] M. Slater, D. Pérez Marcos, H. Ehrsson, M. Sanchez-Vives, Towards a digital body: the virtual arm illusion, Frontiers in Human Neuroscience 2 (6).
URL http://journal.frontiersin.org/article/10.3389/neuro.09.006.2008

[30] D. Banakou, R. Groten, M. Slater, Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes, Proceedings of the National Academy of Sciences 110 (31) (2013) 12846–12851. doi:https://doi.org/10.1073/pnas.1306779110.

[31] K. Kilteni, I. Bergstrom, M. Slater, Drumming in immersive virtual reality: the body shapes the way we play, IEEE transactions on visualization and computer graphics 19 (4) (2013) 597–605. doi:10.1109/TVCG.2013.29.

[32] T. C. Peck, S. Seinfeld, S. M. Aglioti, M. Slater, Putting yourself in the skin of a black avatar reduces implicit racial bias, Consciousness and cognition 22 (3) (2013) 779–787. doi:https://doi.org/10.1016/j.concog.2013.04.016.

[33] M. Gonzalez-Franco, A. Steed, S. Hoogendyk, E. Ofek, Using facial animation to increase the enfacement illusion and avatar self-identification, IEEE Transactions on Visualization and Computer Graphics 26 (5) (2020) 2023–2029. doi:10.1109/TVCG.2020.2973075.

[34] R. Fribourg, F. Argelaguet, L. Hoyet, A. Lécuyer, Studying the sense of embodiment in vr shared experiences, in: 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), 2018, pp. 273–280. doi:10.1109/VR.2018.8448293.

[35] N. Yee, J. Bailenson, The Proteus effect: The effect of transformed self-representation on behavior, Human communication research 33 (3) (2007) 271–290.

[36] N. Yee, J. N. Bailenson, N. Ducheneaut, The Proteus effect: Implications of transformed digital self-representation on online and offline behavior, Communication Research 36 (2) (2009) 285–312.
URL http://dx.doi.org/10.1177/0093650208330254

[37] R. McDonnell, M. Breidt, H. H. Bülthoff, Render me real?: Investigating the effect of render style on the perception of animated virtual humans, ACM Trans. Graph. 31 (4) (2012) 91:1–91:11. doi:10.1145/2185520.2185587.
URL http://doi.acm.org/10.1145/2185520.2185587

[38] M. Mori, K. F. MacDorman, N. Kageki, The uncanny valley [from the field], Robotics & Automation Magazine, IEEE 19 (2) (2012) 98–100. doi:10.1109/MRA.2012.2192811.

[39] J. Seyama, R. S. Nagayama, The uncanny valley: Effect of realism on the impression of artificial human faces, Presence: Teleoperators and Virtual Environments 16 (4) (2007) 337–351. doi:10.1162/pres.16.4.337.

[40] S. Benford, J. Bowers, L. E. Fahlén, C. Greenhalgh, D. Snowdon, Embodiments, avatars, clones and agents for multi-user, multi-sensory virtual worlds, Multimedia Systems 5 (2) (1997) 93–104.

[41] S. Mansour, M. El-Said, C. Rude-Parkins, J. Nandigam, The interactive effect of avatar visual fidelity and behavioral fidelity in the collaborative virtual reality environment on the perception of social interaction, in: Proceedings of the 10th WSEAS International Conference on Communications, ICCOM'06, World Scientific and Engineering Academy and Society (WSEAS), Stevens Point, Wisconsin, USA, 2006, p. 387–395.

[42] R. Eynard, M. Pallot, O. Christmann, S. Richir, Impact of verbal communication on user experience in 3d immersive virtual environments, in: 2015 IEEE International Conference on Engineering, Technology and Innovation/ International Technology Management Conference (ICE/ITMC), 2015, pp. 1–8. doi:10.1109/ICE.2015.7438679.

[43] C. S. Oh, J. N. Bailenson, G. F. Welch, A systematic review of social presence: Definition, antecedents, and implications, Frontiers in Robotics and AI 5 (2018) 114. doi:10.3389/frobt.2018.00114
URL https://www.frontiersin.org/article/10.3389/frobt.2018.00114

[44] Y. Wu, Y. Wang, S. Jung, S. Hoermann, R. W. Lindeman, Exploring the use of a robust depth-sensor-based avatar control system and its effects on communication behaviors, in: 25th ACM Symposium on Virtual Reality Software and Technology, VRST '19, Association for Computing Machinery, New York, NY, USA, 2019. doi:10.1145/3359996.3364267
URL https://doi.org/10.1145/3359996.3364267

[45] T. Chaminade, J. Hodgins, M. Kawato, Anthropomorphism in-

12

fluences perception of computer-animated characters' actions. Social Cognitive and Affective Neuroscience 2 (3) (2007) 206–216. arXiv:https://academic.oup.com/scan/article-pdf/2/3/206/27104993/nsm017.pdf, doi:10.1093/scan/nsm017. URL https://doi.org/10.1093/scan/nsm017

[46] A.-S. Milcent, E. Geslin, A. Kadri, S. Richir, Expressive virtual human: Impact of expressive wrinkles and pupillary size on emotion recognition, in: Proceedings of the 19th ACM International Conference on Intelligent Virtual Agents, IVA '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 215–217. doi:10.1145/3308532.3329446. URL https://doi.org/10.1145/3308532.3329446

[47] Z. Li, X. Mao, L. Liu, Providing expressive eye movement to virtual agents, in: Proceedings of the 2009 International Conference on Multimodal Interfaces, ICMI-MLMI '09, Association for Computing Machinery, New York, NY, USA, 2009, p. 241–244. doi:10.1145/1647314.1647367. URL https://doi.org/10.1145/1647314.1647367

[48] J. Rekimoto, K. Uragaki, K. Yamada, Behind-the-mask: A face-through head-mounted display, in: Proceedings of the 2018 International Conference on Advanced Visual Interfaces, AVI '18, Association for Computing Machinery, New York, NY, USA, 2018. doi:10.1145/3206505.3206544. URL https://doi.org/10.1145/3206505.3206544

[49] M. Garau, M. Slater, S. Bee, M. A. Sasse, The impact of eye gaze on communication using humanoid avatars, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '01, Association for Computing Machinery, New York, NY, USA, 2001, p. 309–316. doi:10.1145/365024.365121. URL https://doi.org/10.1145/365024.365121

[50] D. Roth, P. Kullmann, G. Bente, D. Gall, M. E. Latoschik, Effects of hybrid and synthetic social gaze in avatar-mediated interactions, in: 2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), 2018, pp. 103–108. doi:10.1109/ISMAR-Adjunct.2018.00044.

[51] J. Casanueva, E. Blake, The Effects of Avatars on Co-presence in a Collaborative Virtual Environment, in: Hardware, Software and Peopleware: Proceedings of the Annual Conference of the South African Institute of Computer Scientists and Information Technologists, 2001.

[52] F. Biocca, C. Harms, Defining and measuring social presence: Contribution to the networked minds theory and measure, Proceedings of PRESENCE 2002 (2002) 7–36.

[53] J. Fox, S. J. Ahn, J. H. Janssen, L. Yeykelis, K. Y. Segovia, J. N. Bailenson, Avatars Versus Agents: A Meta-Analysis Quantifying the Effect of Agency on Social Influence, Human–Computer Interaction 30 (5) (2014) 401–432. doi:https://doi.org/10.1080/07370024.2014.921494.

[54] C. Harms, F. Biocca, Internal consistency and reliability of the networked minds measure of social presence, in: M. Alcaniz, B. Rey (Eds.), Proceedings of the 2004 Seventh Annual International Workshop: Presence, 2004. URL http://cogprints.org/7026/

[55] E. A. Croes, M. L. Antheunis, A. P. Schouten, E. J. Krahmer, Teasing apart the effect of visibility and physical co-presence to examine the effect of cmc on interpersonal attraction, Computers in Human Behavior 55 (2016) 468 – 476. doi:https://doi.org/10.1016/j.chb.2015.09.037. URL http://www.sciencedirect.com/science/article/pii/S0747563215301680

[56] J. Appel, A. M. Rosenthal-von der Pütten, N. Krämer, J. Gratch, Does humanity matter? analyzing the importance of social cues and perceived agency of a computer system for the emergence of social reactions during human-computer interaction, Advances in Human-Computer Interaction 2012. doi:10.1155/2012/324694.

[57] K. L. Nowak, F. Biocca, The effect of the agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments, Presence: Teleoperators and Virtual Environments 12 (5) (2003) 481–494. doi:10.1162/105474603322761289.

[58] G. Bente, F. Eschenburg, L. Aelker, Effects of simulated gaze on social presence, person perception and personality attribution in avatar-mediated communication, in: Presence 2007: Proceedings of the 10th Annual International Workshop on Presence, October 25-27, 2007, Barcelona, Spain,

Citeseer, 2007, pp. 207–14.

[59] F. Herrera, S. Y. Oh, J. N. Bailenson, Effect of behavioral realism on social interactions inside collaborative virtual environments, PRESENCE: Virtual and Augmented Reality 27 (2) (2020) 163–182. arXiv:https://doi.org/10.1162/pres_a_00324, doi:10.1162/pres_a_00324. URL https://doi.org/10.1162/pres_a_00324

[60] P. Heidicker, E. Langbehn, F. Steinicke, Influence of avatar appearance on presence in social vr, in: 2017 IEEE Symposium on 3D User Interfaces (3DUI), 2017, pp. 233–234. doi:10.1109/3DUI.2017.7893357.

[61] S. W. Greenwald, Z. Wang, M. Funk, P. Maes, Investigating social presence and communication with embodied avatars in room-scale virtual reality, in: D. Beck, C. Allison, L. Morgado, J. Pirker, F. Khosmood, J. Richter, C. Gütl (Eds.), Immersive Learning Research Network, Springer International Publishing, Cham, 2017, pp. 75–90. doi:10.1007/978-3-319-60633-0_7.

[62] E. Kokkinara, R. McDonnell, Animation realism affects perceived character appeal of a self-virtual face, in: Proceedings of the 8th ACM SIGGRAPH Conference on Motion in Games, MIG '15, Association for Computing Machinery, New York, NY, USA, 2015, p. 221–226. doi:10.1145/2822013.2822035. URL https://doi.org/10.1145/2822013.2822035

[63] L. Herrewijn, K. Poels, The impact of social setting on the recall and recognition of in-game advertising, Computers in Human Behavior 53 (2015) 544–555. doi:https://doi.org/10.1016/j.chb.2014.06.012.

13