Petting a cat helps you incarnate the avatar: Influence on the emotions over embodiment in VR

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Figure 1: The stimuli used for the positive and negative emotions, respectively with a cat to pet on the left, and a box of insects on the right

Abstract

Thanks to its strong capacity to immerse users in virtual worlds, virtual reality can elicit various emotions with diverse environments. This aspect of virtual reality makes it an interesting and powerful tool in many fields, such as entertainment with scenarios based on a strong emotional implication, training in particular for social or communication skills, or even medical therapy with phobia or addiction treatment. However, in virtual reality the participant lives the experience through an avatar, and feels the emotion according to what happens to this avatar.

This paper discusses the link between embodiment and emotional implication in virtual reality. In particular, we looked at how emotions and the sense of embodiment are correlated in virtual reality. Through an experiment, we demonstrate that the sense of embodiment is strongly correlated with the emotional experience of the virtual environment. The sense of embodiment is increased when the virtual scenarios make the participants feel strong emotions, whether those emotions are positive or negative. We also show that emotions mainly affects two sub-components of embodiment : the appearance and response sub-scales.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Computing methodologies—Computer graphics—Graphics systems and interfaces—Perception; Human-centered computing—Human computer interaction (HCI)—Empirical studies in HCI

1 Introduction

Virtual reality is an important asset for many domains, such as education. Indeed, it has already demonstrated several times its potential for teaching applications [3]. The use of virtual reality for teaching is interesting because of its capacity to create various controlled and ecological situations, with limited risk. Another advantage of virtual reality in those applications could be the emotional implication it allows, which is of strong importance for learning purposes [30].

Virtual reality bears the capacity to elicit a strong sense of self-representation in the virtual environment, mainly via the feeling of presence, i.e. the feeling of being physically and spatially located in an environment and the sense of embodiment, i.e the feeling of owning the virtual body as one's own. Presence and embodiment are interacting high cognitive level processes [23]. As such, they also interact with other cognitive processes, such as emotions [8]. Indeed, the reinforcement of the sense of presence [5] has been shown to faciitate the feeling of stronger emotions [24]. Likewise, the sense of embodiment [14] could be an important part of the emotional implication during virtual reality scenarios. Indeed, the sense of embodiment is strongly linked with how the users perceive themselves in virtual reality, and the perception of oneself has the ability to change the emotions elicited by various scenarios.

However, the possible link between emotions and the sense of embodiment in virtual reality still needs to be investigated. In this paper, we demonstrate the influence of strong emotions on the sense of embodiment, through a virtual reality experiment. The experiment simulates different emotional stimuli, presented with different avatars spanning from a partial abstract to a full realistic one. Those avatars are used with three emotional conditions of positive, negative and neutral valence: a cat to pet, a box of insects and a simple problem resolution task (see Fig. 1).

This experiment was conducted with 30 participants, and showed that virtual environment with strong emotional stimuli increase the sense of embodiment.

2 Related works

In virtual reality, one of the key elements of the subjective virtual experience is the sense of embodiment. What makes it paramount for a large set of VR applications requiring a user's active participation is that it allows the user to appropriate the virtual body, which is the main entry point to the virtual environment [14]. The subjective sense of owning the virtual body has been shown to be an essential element for the successful use of VR for behavioural cognitive therapy [16] or learning [28]. It has also been shown that embodiment in its whole reinforces the feeling of presence, which is another key factor of virtual reality [24], even if that can be questioned [10]

However, it is still difficult to pinpoint the link between embodiment and the nature and characteristic of the virtual experience proposed to the user. More specifically, we are interested in the potential connections between the sense of embodiment and the emotional implication in the virtual environment. Many studies uses emotional arousal to study embodiment. However they mainly use behavioural responses, like body movement after physical threat, as a mean of evaluating the sense of embodiment through the fear

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of endangering one's incarnated body [2, 7]. They do not study the relation between emotion arousal, dominance and valence and the sense of embodiment, which only gives a partial information of the relation between emotional states and embodiment. Also, it should be noted that the works on the subject of emotion in virtual reality are mostly focused on negative emotions or emotions that are not valence-based and choose to focus on arousal through stress and fear [20]. The control element of the emotion is rarely taken into account even though it is an important element to differentiate some emotions, for instance fear and anger [29], or to determine how the user's body is involved in the emotion.

Embodiment is decomposed into several sub-components. Kilteni et al. propose to decompose it into agency, ownership and self-location [14] while Peck et al. propose [21] the following sub-components: appearance, response, ownership, multi-sensory and agency. Each of these components contribute to the overall sense of embodiment [11] in an inter-weaved and complex relation which differs by participant and by scenario.

Regarding the emotions, virtual reality has been shown to reinforce the emotional response when compared to a more traditional medium. For instance, this effect has been described by Allcoat and von Mühlenen for the context of virtual reality for learning [1], for which participants reported more positive emotions, and a decrease in negative ones, when using virtual reality instead of regular video and textbook content. This increase in positive emotion is also noticed in Knaust et al.'s work for the case of self-reported relaxation, although it could not be validated by objective physiological indicators [15]. Negative emotions, and particularly fear and threat, seem to be more strongly felt in virtual reality, with a possible link to the sense of presence [17]. However, this link is still questioned, as some other studies report the same level of presence despite using environments with different emotional stimuli [10].

To summarize the related works, we can say that although emotions bear a strong importance in virtual reality, their impact on embodiment has not yet been researched. When studying embodiment negative emotions are mainly used to induce behavioral responses that are analyzed as an indicator of embodiment. On the other hand, emotional responses have been used as an indicator of the efficiency of a given virtual environment. But as of today, the relationship between emotions and embodiment has not been thoroughly investigated.

3 Hypotheses and experimental setup

In this paper, our main purpose is to understand the interactions between the emotions felt during a virtual reality immersion and the sense of embodiment. More precisely, we want to pinpoint a relation between the 3 dimensions of the emotions (arousal, valence and control, [6]) and the sense of embodiment.

To this end, we formulate two hypotheses. The first one is that, since a greater presence and immersion seem to lead to emotions felt more strongly [8], a greater sense of body ownership would also lead to more intense emotions.

Our second hypothesis is that the valence of the emotion (i.e. whether the emotion is positive or negative) may have an importance in the impact between ownership and emotion intensity. To be able to verify those two hypotheses, we define two additional hypotheses to validate the design of the virtual environment used in the experiment. First, the environments must elicit the targeted emotions, to ensure that the comparisons are valid. The second hypothesis for the validation of our environment is that changing the avatar has an impact on the sens of embodiment.

Hence, we can summarize the following working hypotheses:

- H_1 The environments succeeds at eliciting emotions with expected valence and arousal: high valence and arousal for the positive emotion, low valence and high arousal for the negative one, and low arousal for the neutral one.
- H_2 More realistic avatars (with increasing realism: PA, PR, FA, FR) generate stronger levels of embodiment.
- H_3 Eliciting a stronger emotion, with high arousal and extreme (low or high) valence, generates a stronger sense of embodiment.

To validate our hypotheses, we designed a virtual environment with different conditions for the avatars and emotional stimuli. In the next sections, we present the experimental setup we used, with the emotional stimuli in Sect. 3.2, the displayed avatars in Sect. 3.3, and the resulting protocol in Fig. 7.

3.1 Experimental setup

Figure 2: The virtual environment in which the conditions take place (bottom picture), and its real counterpart (top picture)

For the experiment, different environments are presented to the user. All of those environments share the same basis comprising a simple office with four desks, placed in a layout similar to the one in the real room used during the experiment. The user sits at one of those desks – corresponding to their real position in the room, and can see their reflection in a mirror on the wall in the back of the room. Moreover a haptic feedback is ensured by the desk and a monitor which are both colocalized with their real counterpart, as displayed in Fig. 2. This monitor is also used for the neutral emotion condition, and displays a still image of a Windows desktop for the other conditions.

To apply the participant's movement to the avatar, the participant is equipped with a HTC Vive Pro as well as two Vive trackers for hand tracking. The use of the trackers for the hand is motivated by the use of haptic feedback on the hands during the immersion, to

Figure 3: Apparatus used with the participants. The display and sound are ensured by the use of a HTC Vive Pro, and the hands are tracked with two Vive trackers.

elicit strong – and clearly identifiable – emotions during the entirety of the experiment.

3.2 Emotion conditions

To check hypothesis H_1, we designed three environments with different emotions: a positive emotion, a negative emotion, and a neutral one.

For each of the conditions, the user is asked to look at their avatar in the mirror during a complete minute of immersion, to be familiarized with the avatar they are embodied in. After this first minute, the user continues with the emotional stimuli for two more minutes. Depending on the emotional valence targeted by the condition, different stimuli can be proposed: a pleasant interaction to elicit a positive emotion, a disgusting environment for the negative condition, and a questionnaire to occupy the participant's mind during the neutral condition.

3.2.1 Positive emotion

The environment for the positive emotion proposes to pet a cat. After the minute of avatar observation, the cat jumps on the desk, sits on it and stays still to allow the user to pet it. For this condition, the user is asked to pet the cat's back, and a constant purring sound is played to enhance the immersion and positive emotion provided by the environment.

As the hands of the avatar approach the cat, the purring sound is played louder, and the cat raises its head to display its satisfaction, as can be seen in Fig. 4. The goal of this interaction is to involve the user as strongly as possible in the environment, and to make the emotion stronger as the user is involved in the environment. To improve the sensation of petting the cat, a cat plush is also used as a haptic accessory.

3.2.2 Negative emotion

Finally, the negative emotion is ensured by showing a box of insects. The box is already present during the observation phase, but opens only when this phase ends. Once the box opens, a sound of swarming insects is played during the rest of the immersion. The user is asked to repeatedly put their hand in the box to be as involved as possible in the environment.

The interactivity of the environment is here provided by a spider placed in the top-right corner of the box. When the hands of the user approach the spider, it moves to face the closest hand, and takes a more aggressive posture. As in the cat condition, some accessories (i.e. the box, plastic insects and a spider plush) are used to give a haptic feedback to the user, as illustrated in Fig. 4.

3.2.3 Neutral emotion

For the neutral condition, we decided to display a quiz on a screen placed on the desk. The quiz starts after the minute of avatar observation, and goes on for two minutes to keep the user mentally involved in the environment.

The questions asked in the quiz are about geometry rotation (in 2D and 3D), as illustrated in Fig. 5. In order to avoid making the user feel stressed, and to make sure no specific emotion is provoked by getting a correct/wrong answer, the answers are not validated afterwards. To answer the questions, the participant has four colored buzzers in front of him, as shown in Fig. 4. Pressing one of the buzzers with a hand validates the corresponding answer and makes the quiz switch to the next question.

Moreover, since the other conditions imply a user interaction in the environment, the neutral condition makes the user answer to the questions by pressing buttons in the virtual environment, which are also used as haptic accessories for feedback.

3.3 Avatar conditions

To verify the hypotheses H_1 and H_2, we need to make the level of body ownership vary according to the conditions we test. To do this, we decided to use four types of avatars, ranging from a very abstract one to a realistic one, to make the difference noticeable between the conditions.

For the conditions including a full body, we decided to adapt the avatar to the participant's gender. To make the presented gender as comfortable as possible for the participant, their gender is asked at the beginning of the experiment, and the conditions are presented according to this choice during the rest of the session.

From the expected low-ownership avatar to the expected high-level one, the avatars are as follows: a partial abstract body, a partial realistic body, a full abstract body, and a full realistic one.

3.3.1 Partial abstract

The Partial Abstract (PA) avatar has been designed to be as minimalist as possible, to elicit a very weak sense of embodiment. Hence, the partial abstract avatar is comprised of two simple spheres, which are placed at hand's position. More precisely, the center of the spheres is located at the center of the participant's palm.

As illustrated in Fig. 6, the spheres are displayed with a light grey color to make them as neutral as possible in the environment. Since the avatar for this condition is extremely simple, the same avatar is used for both female and male participants in the partial abstract condition.

3.3.2 Partial real

The Partial Real (PR) avatars are represented by two hands, with the arms being cut around the wrist, as shown in Fig. 6. The goal of this avatar is to have more details that the abstract ones with the representation of the fingers, absent from the partial abstract one, and the use of a realistic skin color unlike the full abstract one. Furthermore, the part of the arms that is not cut is covered by sleeves to avoid seeing any visual indicator that would make the hands be identified as female or male.

Since the hands are generic enough, and since it is the only part of the body that is represented in this condition, the same avatar is used for both female and male participants, as in the partial abstract condition.

3.3.3 Full abstract

For the Full Abstract avatars (FA), we decided to use humanoid shaped dummies, to allow the participants to recognize easily the morphology of the avatar. To do this, we chose to use as avatars the models provided by Mixamo [1] for the previews of their animations.

[1] `https://mixamo.com/`

Figure 4: Emotional conditions used for the study. From left to right, the positive, negative and neutral emotions with the cat, insects and buzzers respectively. In the top row are the real environmental setup, while in the bottom row are the virtual counterparts seen by the participants.

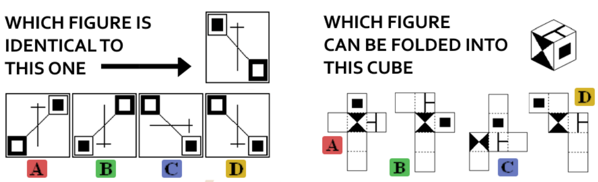

Figure 5: Examples of questions used in the neutral condition

These full abstract avatars are humanoid shaped robots, and are not human skin colored. The female avatar has a light pink color, while the male one comes with a light blue color. Both of those avatars are designed to represent a simplified morphology for its corresponding gender. Hence, the women's dummy is more chested and has thinner arms while the men's one is a bit taller with longer arms. Although they are displayed at the same scale for the sake of illustration in Fig. 6, they are scaled in the virtual environment to correspond to the average female and male height respectively.

3.3.4 Full real

The Full Realistic (FR) avatars are different according to the participant's gender, as seen in Fig. 6. For female participants, the full realistic avatar is a young woman dressed with a white t-shirt and jeans. The male avatar is a young man wearing a dark blue suit.

Like the full abstract bodies, the full realistic ones are also scaled according to the genders average height they are to represent. Those two models were chosen to avoid bodies with too salient features, which would make some participants have difficulties identifying with the virtual body.

3.4 Protocol

After welcoming the participants, the protocol is presented and explained to them. After that, their consent is collected, and they are asked to fill two questionnaires. The first questionnaire aims at evaluating their sociological profile (age, gender, familiarity with video games and VR). The second questionnaire is the Simulator Sickness Questionnaire (or SSQ) [13] to check their sickness level before the experiment.

After that, the participant is immersed 6 times in VR with various avatar and emotional conditions. The 6 conditions chosen for each participants are determined through a Latin square method, ensuring that each participant gets twice each emotion and that the avatars are balanced between the participants. This Latin square is generated from the line (NPA, CFA, IPR, NFR, CPR, IFR, NFA, CFR, IPA, NPR, CPA, IFA[2]), and each line is divided in two halves to define 6 conditions per participant. We chose the Peck et al. standardized questionnaire [21] over the Roth et al. questionnaire [25] because we thought it allowed a richer and more precise evaluation of the dimensions of embodiment and the change aspect of Roth and Latoschik questionnaire was deemed less pertinent for our experiment. After each immersion in the virtual environment with the corresponding avatar and emotion, the participant assesses their emotion with the Self-Assessment Manikin (or SAM) [6] – which rates emotion Arousal, Valence and Dominance from 1 to 9, and their sense of embodiment with the Avatar Embodiment Questionnaire [21].

Finally, the participant fills the SSQ a second time to ensure that the immersion sessions did not make them sick, and is asked to assess their sense of presence with the Presence Questionnaire [31].

4 Results and Discussion

We tested our protocol with 30 participants (4 female and 26 male) aged between 18 and 58 (mean=26,3, sd=9,78). Most of them use virtual reality rarely (answers ranking from ”never” to ”daily use”).

Before the experiment, participants were asked if they had any form of ailurophobia or entomophobia, to prevent triggering those fears with the virtual environments (respectively with the positive and negative emotions).

Analysis of the SSQ and presence questionnaire allow us to validate the protocol. Indeed, the SSQ results, described in Fig. 8, show that the participants did not feel any significant simulator sickness. Regarding the presence, total scores at the Presence Questionnaire with sound [31] gave results between 71 and 125 (mean=99.03, sd=12.52), showing that the environment was deemed realistic enough by the participants.

[2]N=Neutral, C=Cat, I=Insect; P=Partial avatar, F=Full avatar; A=Abstract avatar, R=Realistic avatar

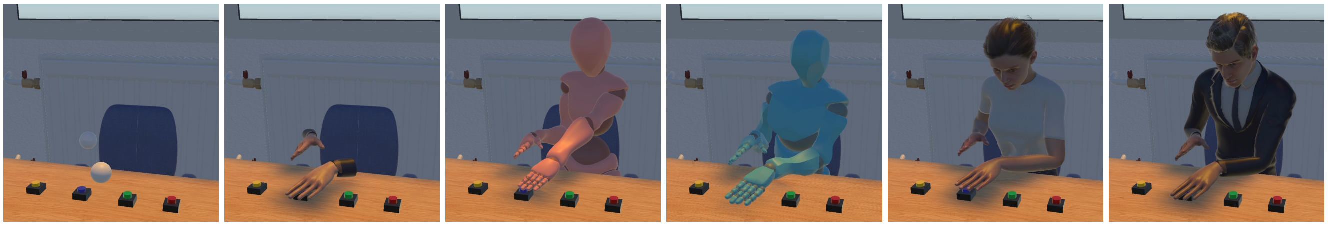

Figure 6: Avatars used during the study. From left to right, the partial abstract avatar (only two spheres for the hands), the partial realistic avatar (two hands), the full abstracts avatars for female and male participants, and the full realistic avatars for female and male participants

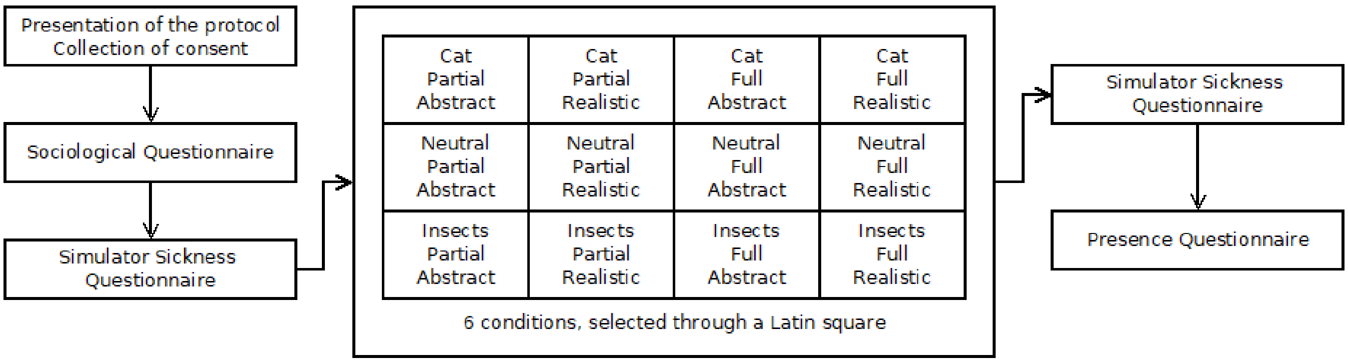

Figure 7: Protocol applied during the experiment

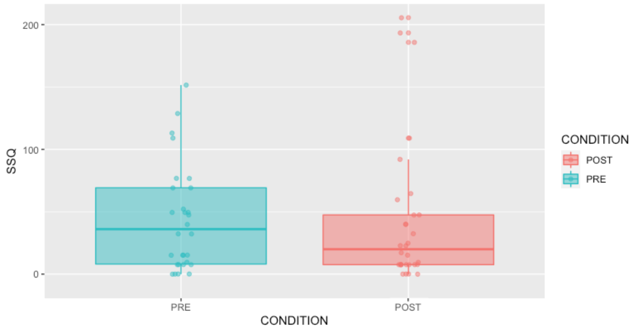

Figure 8: Scores for the SSQ post and pre experiment

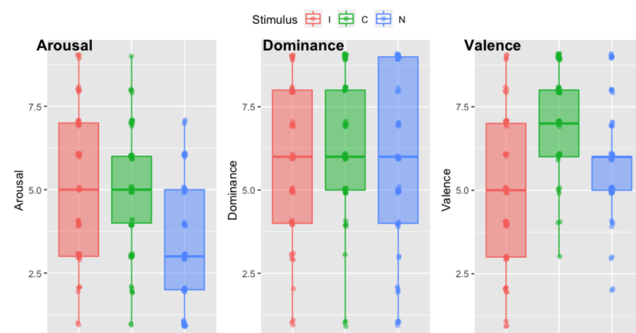

Figure 9: SAM results per emotional condition

4.1 Inducing emotions

We used The Aligned-Rank Transform (ART) method to analyse likert-scale data. ART allows for non-parametric analyses of variance [9,32]. We used the ARTool [3] package in RStudio to perform the analysis [12]. Running our analysis, we looked at the influence of the emotional stimulus condition on emotion arousal, valence and control reported by the participants using the Self Assessment Manikin questionnaire [6]. Our objective was to verify that our experimental setup gave the expected results in terms of emotion induction, to validate our hypothesis H_1.

We found a significant main effect of the stimulus condition on emotional arousal (F(2)=13.031, p = 1.3073e-05), valence (F(2)=36.804, p = 1.4031e-13) and control (F(2)=3.586, p = 0.0302). Post-hoc tests reveal that pairwise comparison differ according to the considered emotional dimension (all pairwise comparison results are reported in the Table 1).

Overall, these results suggest that our two emotion inducing conditions (Cat and Insects) differ from the reference (neutral) condition for valence and intensity. Both the Cat and Insects condition led to higher arousal levels than the neutral condition (see Fig. 9). Regarding valence, there is a significant difference between Cat and Insects that confirm that the stimuli were able to generate contradictory emotions in the participants, but there is no significant difference with the neutral condition. Finally, regarding dominance we found a significant difference between Cat and Insects that suggests that the participants had a higher dominance over positive emotions.

These results suggest that our environments succeeded in inducing the desired emotions in the participants with the Cat (positive) condition leading to intense and positive emotions while the Insect (negative) condition led to intense and negative emotions.

4.2 Sense of embodiment

For the analysis of the effects of avatar conditions on embodiment, we performed a factorial ANOVA using linear mixed models [22]. We analysed embodiment and its dimensions separately, using the avatar condition as the independent variable. We introduced the

[3] `https://cran.r-project.org/package=ARTool`

	Valence	Dominance	Arousal
I-C	**-63.1 (<0.0001)**	-18.48 (0.0235)	-0.233 (0.9993)
I-N	-19.6 (0.0274)	-7.48 (0.5271)	**44.385 (<0.0001)**
C-N	**43.5 (<0.0001)**	11.00 (0.2506)	**44.618 (<0.0001)**

Table 1: Pairwise contrast estimate of the emotion according to the stimuli, with the difference, and p-value in parentheses

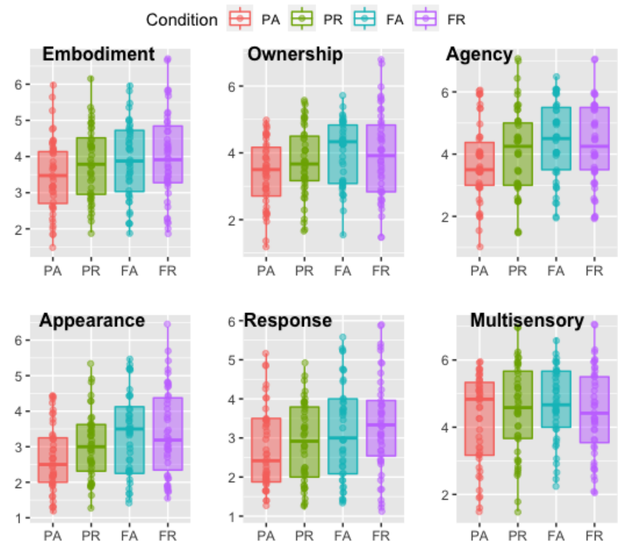

Figure 10: Embodiment (and its separate components) for each avatar condition

participants as a random effect to take into account repeated measures. These analysis were performed using the nlme package [4]. Post-hoc comparisons were performed using contrast methods with the emmeans R package [18].

The results indicate that the avatar has an impact on the sense of embodiment and all its sub-components (ownership, agency, appearance, response and multi-sensory - see 2 and Fig. 10) as measured by the Avatar Embodiment Questionnaire [21]. Post-hoc comparisons show that the Partial Abstract (PA) avatar condition led to a significantly lower sense of embodiment than the Patrial Real (PR), Full Abstract (FA) and Full Real (FR) conditions (see 3 and 10). However we found no significant difference between the PR, FA and FR conditions. Regarding sub-components of embodiment, we can see that - not surprisingly - Appearance is the factor that is mostly impacted by the avatar conditions, all conditions being significantly different except the FR and FA conditions, with PA < PR < FA and FR.

We can then validate our hypothesis H_2. Taken overall, since we found no significant difference whatsoever between FA and FR avatar conditions, our results suggest that having a full-body avatar is more important to embodiment than having a realistic one. However, we need to stress that if we found different level of embodiment between our conditions, only the PA condition led to a significantly lower embodiment than all other conditions and that differences differ throughout the sub-components of embodiment. We think that we might have observed stronger differences between the avatar conditions if the participants have had control on their virtual fingers during the experiment, especially with the real avatars. Indeed, as the hands are tracked only with the Vive trackers, the pose of the fingers is not reproduced in the virtual environment. Furthermore,

[4]`https://cran.r-project.org/package=nlme`

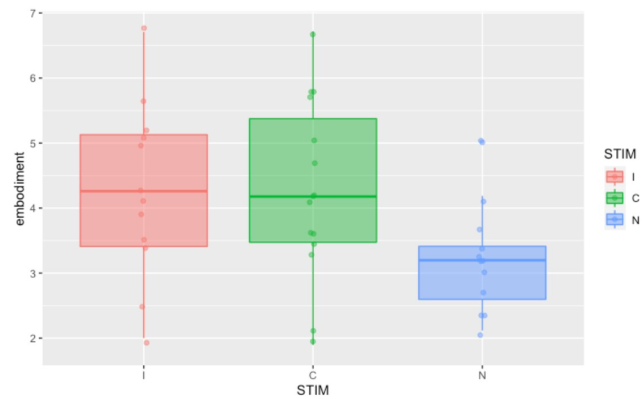

Figure 11: Embodiment measurement for each emotion condition

we choose to display the hands in rather neutral poses, to avoid making too much assertions on how the hands of the participants were during the session.

4.3 Influence of emotion on embodiment

Our third hypothesis states that inducing an emotion leads to a higher sense of embodiment. To validate this hypothesis, we calculated the correlation matrix between emotion sub-scales and embodiment sub-scales using the R *cor* function. Statistical significance of the correlations were calculated using the *RCOR* function from the HMISC package [5]. Finally, we calculated pairwise comparisons using the *Cocor* R package considering our data to be dependent and overlapping. We ran multiple tests, for each dimension of emotional response: arousal, dominance, and valence, to compare their effect on embodiment and its sub-scales.

We present the results of the calculated correlations in Table 4. We chose not to report here the results concerning emotional valence, since no correlation were found with any sub-component. Moreover, when we looked at the influence of valance on embodiment, we found no significant influence whatsoever (results are not reported here for the sake of brevity), suggesting that valence does not affect embodiment and that any interaction between emotion and embodiment are linked to arousal and dominance whether the given emotion is positive or negative (see Fig. 11).

Correlation coefficients (see Table 4) show that emotional arousal and dominance are positively correlated with several dimensions of embodiment. The results report a significant correlation between arousal and embodiment, agency, appearance and response. The correlation is strong for overall embodiment, moderate for appearance and response, and small for agency. Dominance is significantly correlated with appearance, response, multi-sensory and ownership, however all correlations are small.

Pairwise comparison between correlations indicate significant difference between response and agency (p<.0001), appearance (p=0.058), multi-sensory (p<.0001) and ownership (p<.0001), suggesting that emotion induction has a significantly higher correlation with this dimension of embodiment compared to all other sub-components. Arousal also has a significantly higher correlation to appearance when compared to agency (p=0.0009), multi-sensory (p<.0001) and ownership (p<.0001). These results suggest that the strong correlation between embodiment and arousal is mainly explained by the correlation between arousal and appearance and response (see Fig. 12).

With those results, as seen in Fig. 11, we can draw the conclusion that emotion has an impact on embodiment whatever the valence of

[5]`https://cran.r-project.org/web/packages/Hmisc/index.html`

	Embodiment	**Ownership**	**Agency**	**Appearance**	**Response**	**Multisensory**
Avatar condition	**F(3)=7.84 p=1e-04**	**F(3)=13.78 p<1e-04**	**F(3)=9.47 p<1e-04**	**F(3)=23.12 p<1e-04**	**F(3)=7.96 p=1e-04**	**F(3)=7.21 p=2e-04**

Table 2: Comparison of avatar conditions (F and p value) for embodiment and its components

Pairwise comparisons	**Embodiment**	**Ownership**	**Agency**	**Appearance**	**Response**	**Multisensory**
PA-FA	**p=0.0022**	**p<.0001**	**p<.0001**	**p<.0001**	**p=0.0132**	**p=0.0438**
FA-FR	p=0.735	p=0.635	p=0.999	p=0.7731	p=0.369	p=0.993
FA-PR	p=0.782	p=0.395	**p=0.0115**	**p=0.0438**	p=0.515	p=0.789
PA-FR	**p=0.0001**	**p<.0001**	**p=.0001**	**p<.0001**	**p<.0001**	p=0.0744
PA-PR	**p=0.034**	**p=0.0047**	**p=0.0704**	**p=0.0003**	p=0.303	p=0.2174
FR-PR	p=0.185	**p=0.027**	p=0.141	**p=0.0018**	**p=0.0131**	p=0.611

Table 3: Comparison of avatar conditions (F and p value) for embodiment and its components.

Correlation	**Embodiment**	**Agency**	**Appearance**	**Response**	**Multisensory**	**Ownership**
Arousal	**0.75**	0.18	**0.37**	**0.48**	0.12	0.14
Dominance	0.21	0.13	0.21	0.19	0.26	0.21
p-value	**Embodiment**	**Agency**	**Appearance**	**Response**	**Multisensory**	**Ownership**
Arousal	**<0.0001**	**0.0147**	**<0.0001**	**<0.0001**	0.1134	0.0595
Dominance	**0.0049**	0.0801	**0.0039**	**0.0121**	**0.0004**	**0.0038**

Table 4: Correlation matrix between emotion (reported with the SAM questionnaire) and embodiment, with the corresponding p-values. Since the emotions were used with both positive and negative valence, the correlation is not used

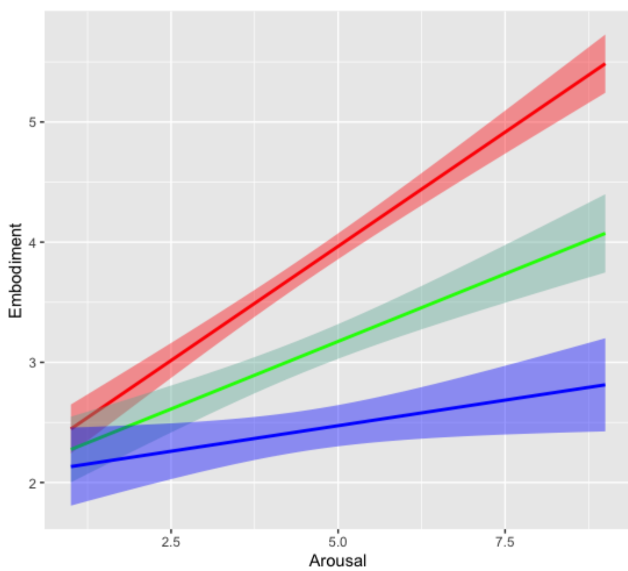

Figure 12: Correlations between arousal and embodiment subscales with confidence intervals. the red line represents overall embodiment, the green line represents mean value for Response and Appearance, the blue line represents mean value for Agency, Multi-sensory and Ownership from the SAM questionnaire.

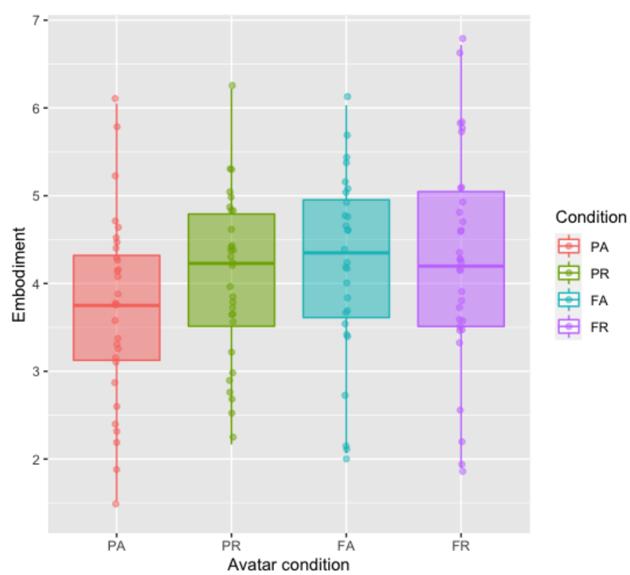

Figure 13: Embodiment for each avatar condition for the emotion inducing conditions Cat and Insects.

the emotion. In particular, the correlation is stronger for the arousal scale of the emotion. This validates our hypothesis H_3, as a strong emotion will cause a stronger embodiment.

Furthermore, it seems that the increase in the sense of embodiment elicited by emotion induction might not depend on the realism of the avatar, assuming that the avatars provides sufficient sensory clues. Indeed, when we compared embodiment considering only the Cat and Insects conditions, we only found a significant difference between PA and PR (p=0.048), FA (p=0.001) and FR (p=0.0001) Fig. 13. This result suggests that an average avatar might be sufficient to generate a strong sense of embodiment as long as an intense enough emotion is elicited by the environment.

4.4 Discussion

Our main objective with this experiment was to study the influence of inducing emotion on the sense of embodiment. We first demonstrated that our three emotion inducing environments were able to solicit the expected emotion within our participant. Our results show that both the Cat and Insects conditions led to a higher emotional response than the Neutral condition. We then studied the difference in embodiment between our four avatar condition : Partial Abstract, Partial Real, Full Abstract, Full Real. To that regard, only the Partial Abstract condition showed significantly lower sense of embodiment.

Concerning the main hypothesis, we observe that inducing an emotion within the participants had a significant effect on embodiment with a strong positive correlation between the two. This suggests that embodiment can be increased through emotions, be it negative or positive. Consequently, the sense of embodiment could be elicited through the induction of positive emotions, in contexts were negative emotions might prove counterproductive. For example, the sense of embodiment could be studied not only through intense negative emotions (for example fear or physical threat, [2]) but also through intense positive emotions. This could allow to overcome some ethical or experimental issues in the current practices regarding the study of the sense of embodiment. For example, in application areas such as mindfulness with VR, increasing embodiment could increase the beneficial effects of the practice and it is probable that negative emotions would oppose the intended purpose [27].

Looking at the sub-components of embodiment, our results show that the appearance and response sub-components are the most strongly correlated to emotion. We found this result particularly interesting since these two categories represent the capacity of the participant to project into is virtual avatar and to merge both physical and virtual body. It thus represent their capacity to feel a change in their physical body through the virtual impersonation and to appropriate these changes. As a consequence, inducing emotions in VR might not only be an appropriate way of potentiating embodiment but might also increase potential effects of VR in several application fields. More specifically, we think that any VR application that need a high sense of response and appearance may benefit from the induction of a strong emotional experience, be it for example a collaborative environment, a learning environment or a cognitive behavioural therapy environment.

5 Conclusion and future works

In this paper, we have shown that eliciting emotions in a virtual environment impacts positively the sense of embodiment. Indeed, strong emotions tend to induce a stronger sense of embodiment, mainly through the components of response and appearance.

Those results could help in defining virtual environments for applications in entertainment, training and therapy for instance, as it gives insight as to how a user can be emotionally involved in the application: creating a scenario with clearly identifiable emotions helps to increase the sense of embodiment on the condition that the user avatar bears realistic enough features.

Based on these promising results, we plan to continue our work to better understand the influence of emotions on the sense of embodiment. We will focus our oncoming work on addressing several limitations of the present study. The first one is the lack of gender and ethnic diversity in the participants panel, due to enrolment issues during the pandemic. We will tackle this issue by going on with our tests in the coming months. Furthermore, having more participants will allow us to analyse potential interactions between avatar body completeness and avatar realism. Finally, we will analyse emotional responses through physiological data that we collected during the experiment (EDA, HRV and EMG), which we did not address in the present paper, and that are known to be relevant measures for emotional responses, especially arousal. This might give us more precise insights on the interactions between avatar representation, emotions and sense of embodiment.

We will then proceed by focusing on the improvement of our avatar conditions to provide more significant differences in the embodiment level. To that regard, we think that adding a way of tracking the participants fingers might be important. Moreover, we would like to introduce new negative emotions conditions, to elicit stronger negative feelings. Indeed, the insect condition gave mixed results depending on the relation the participants had with insects: some of them had a clear fear of insects, while some of them had little feelings regarding them.

We would also like to investigate more deeply other aspects of the sense of embodiment notably the agency sub-component, which is linked to the control the user has on the avatar's movements. Indeed, some users noted that one of the reasons they felt the emotions strongly was the ability to act on the virtual world, which made them think that the emotion was initiated by their actions. By introducing new interaction opportunities in our environment, we might be able to better understand the relations between agency and emotions.

Finally, our long term objective is to study the impact of inducing positive emotions on the practical outcomes of using VR, especially in the fields were a higher sense of embodiment might bear a significant effect, mainly cognitive behavioural therapy, for example for the treatment of social phobia [26]), mindfulness [27], empathy [4] and learning [19].

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