Where is my Self ?

Julien Racle (PH), Jonathan Rentsch (PH), Pascal Resin (IN),
Fabienne Riche (SV), Simon Ruffieux (IN)

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Encadré par

Bigna Lenggenhager (conceptual), Tej Tadi (technical), Laura Bamert (conceptual) et professeur Olaf Blanke (LNCO, EPFL)

Psychologie cognitive,

responsable Fred Mast (Unil)

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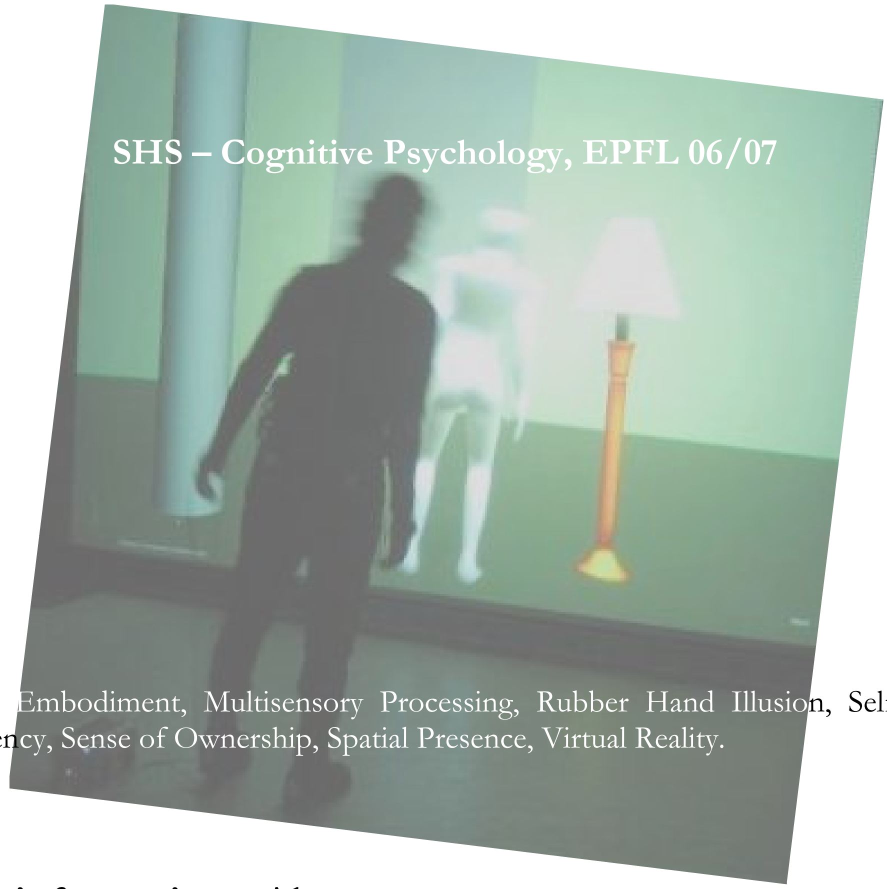
Experimentally Induced "Whole Body Illusions" in Healthy Subjects using Virtual Reality

Students : Fabienne Riche, Pascal Resin, Simon Ruffieux, Julien Racle, Jonathan Rentsch
Supervision : Bigna Lenggenhager (conceptual), Tej Tadi (technical), Laura Bamert (conceptual)
Professors : Olaf Blanke (LNCO, EPFL), Fred Mast (Cognitive Psychology, Unil)



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Key words: Embodiment, Multisensory Processing, Rubber Hand Illusion, Self-localisation, Sense of Agency, Sense of Ownership, Spatial Presence, Virtual Reality.

Auxiliary information - Abstract:

This student's project is meant to support the collection of experiments for the PHD thesis of the above mentioned supervisors and as part of this framework also accounts for the student's credits for their Masters. Based on recent research in cognitive psychology, more precisely on the topics of *sense of ownership* and the *sense of agency*, this project seeks to reveal a whole body illusion, as an extension of the well-known "rubber hand illusion" (RHI) experiment. Simultaneously it ought to contribute to a clearer understanding of visual, somatosensory and motor influences on bodily self perception by systematically disentangling these latter components. Through the use of recently developed and state of the art techniques, such as *virtual reality* and *whole body tracking*, this project attempts to take advantage of new technologies for investigating the self.

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1 Introduction

One of the biggest research quests of our times is to fully understand the human brain and its mechanisms. New technologies have opened the doors to explore our mind, as for example by the use of virtual reality (VR). This technique is a powerful tool as it allows one to put the subjects into situations that could hardly be done in real life, and to vary systematically parameters such as for example the visual properties of the virtual character or the external environment. Further-on studies on spatial presence in virtual reality have shown that subjects tend to identify themselves with a virtual character in a VR environment (e.g. Sanchez-Vives and Slater [1]). This opens new possibilities to change the subject's functional body (interaction between body and environment) without changing the real body.

In this experiment, we are mainly interested in bodily self perception and body ownership (self attribution of one's body / body parts). It refers to the spatial perceptual status of one's own body, which makes bodily sensations seem unique to oneself. Perception of the body is a multi-sensorial integration process where the brain has to integrate tactile, proprioceptive, visual and vestibular information in order to create a coherent representation of the body. This integration seems to depend on bottom-up (sensory input) as well as on top-down (representation of the body) processes [2]. Because neural integration of vision and touch may be essential for developing and maintaining this sense of bodily self, modifying their perception through VR is an interesting way to study the attribution of our sense of our own body [3].

2 Literature Review

Many of the referenced articles point out a potential, resulting from amalgamation of the use of virtual reality (VR) and the understanding of the self (e.g. Sanchez-Vives and Slater [1]). Especially the possibility to modify one's sensations in the VR environment can be very useful. The synthesis of these two domains might open a whole new set of research questions and psychological therapy techniques. As an example we can cite phobia treatment where VR is already used.

Until now, bodily self and ownership has mostly been studied in clinical patients (Blanke et al. [4]) Yet, some research has been done in healthy subjects using some body illusions. One such famous illusion is the rubber hand illusion which was first described by Botvinick and Cohen [5]. This illusion is created in the following way: the subject's arm lies on a table but is hidden from his view. And then the experimenter strokes at the same time the hand of the subject and a visible fake hand. Usually, the subject will be taking the fake arm for his own arm. A hypothesis to explain this, is that the subject's brain, seeing the stroked fake hand and feeling a stroking at exactly the same time, thinks that these sensory inputs are coming from the same event. Different variations of the RHI experiment followed. For example Armel and Ramachandran [6] were interested in how flexible the body schema is and tried the RHI, simply using the table for the fake hand, or putting the fake hand at an impossible position in comparison with the rest of the body, and they found that the illusion was still present. This led them to argue that the illusion arises mainly from the brain's ability to detect statistical correlations in sensory inputs to construct useful perceptual representations of the world (including one's body). In addition, Tsakiris and Haggard [7] showed that RHIs with tactile stimulation led to a fragmented body awareness (stimulating only one finger (of the fake and real hand), they obtained that only the stimulated fake finger was integrated in the body). Next, using this illusion, they investigated whether active and passive movements would lead to a similar fragmented body awareness, in order to see how motor agency in the voluntary control of body movements influences body awareness. They found that while purely proprioceptive sense of body-ownership is local and fragmented, the motor sense of agency integrates distinct body-parts into a coherent, unified awareness of the body.

In another experiment, Tsakiris et al. [8] distinguish between the causes (i.e. multi-sensory stimulation) and the effect (i.e. the feeling of ownership) of the RHI. Using PET scan they identified brain areas whose activity was correlated with a measure of body ownership (they found body ownership was related to activity in the right posterior insula and the right frontal operculum). A further example for the use of the RHI to study bodily cognition is given by Schütz-Bosbach et al. [9] who used it to manipulate the sense of body ownership in order to compare effects of observing actions that were illusorily attributed to the subject's own body and actions that were not attributed to his body. They show that observing another's actions facilitated the motor system, and that, in contrary, observing actions, which were illusorily attributed to the subject's own body, showed the opposite pattern. They thus conclude that motor facilitation strongly depends on the agent to whom the observed action is attributed. This result contradicts previous concepts of equivalence between one's own actions and actions of others and suggests that social differentiation, not equivalence, is characteristic of the human action system.

For example, the observation of another's action can selectively facilitate the brain's motor circuit for the same action. A "mirror-matching mechanism" might map observed actions onto the observer's own motor representations. Crucially, this view suggests that the brain integrates other's actions like one's own [9].

A different and very interesting approach to study the bodily self was done by Japanese philosophers (Sato and Yasuda [10]) who investigated by the mean of a *Head-Mounted-Display* (HMD) long term effects of changing the perspective (seeing ones own body from a third perspective). They proposed that knowledge of motor commands is used to distinguish self-generated sensation from externally generated sensation. They show that the sense of self-agency largely depends on the degree of discrepancy resulting from comparison between the predicted and actual sensory feedback. Their findings suggest that the senses of self-agency and self-ownership are mutually independent.

As we have seen, many experiments have been done using the RHI to get a better knowledge of body-ownership and sense of agency. However, there have been none using the whole body. As the sense of body-ownership coming from the RHI is fragmented, we think that using the body as a whole for an experiment similar to the RHI could give a more complete sense of body-ownership and some new interesting insights in bodily ownership mechanisms. This is the question we propose to answer here, using virtual reality to create the whole body illusion.

3 The present study

3.1 General purpose

The general aim of the study is to extend previous data on a whole body analogue of the rubber hand illusion, here called rubber body illusion (RBI) [11]. In this previous experiment undertaken by Bigna Lenggenhager, the subjects were stroked on the back while standing still, and with the help of a camera and a head mounted display (HMD), they could simultaneously see themselves being stroked. If the illusion was present, they were tempted to identify themselves to the character seen in the HMD.

With our illusion, we try to systematically disentangle the influences of visual, somatosensory and motor components on bodily self perception such as the sense of ownership, the sense of agency and spatial presence for the whole body.

The use of a tracking system has several advantages compared to previous setups of rubber hand and preparatory whole body illusion experiments described above. Mainly, we can easily control the time lag, measure more precisely the distance between the subject and the virtual character and also be able to localize the stroking and the spatial location of the subject. It also gives other possibilities which we will not use in our experience, but that will be very useful for further research at the LNCO: size, position, view etc. of the displayed virtual character and environment can be modified with ease, or disturbing effects such as mirrored, exaggerated movements could also be added.

The main question is "to what extent the subject attributes the virtual body to his own body and how does this influence the self localization of ones own body". If the experiments work, we would ideally be able to measure which intermodal (visual - somatosensory, visual-active/passive motor) correlations are more relevant for the self-identification. This would have important implications for scientific explanations of different concepts such as embodiment or spatial presence; but also for clinical phenomena such as autoscopic phenomena.

3.2 Experiment A: Stroking

This experiment is the modification to the whole body of the rubber hand illusion experiment. The subject stands straight, without moving, within the limits of the tracking frame. A second person strokes the subject in the upper part of his back using a stick (brush). The subject looks at a life size virtual character, shown from a back view, distant of two meters in front of him. The stroking was tracked (the stick has sensors on it so that the tracking frame knows exactly its position and orientation) and could then be projected in real-time on the back of the virtual character. Two conditions were tested here: (1)

the projected stroking is perfectly synchronous with the real one (except the very small time lag of the equipment), (2) the stroking is asynchronous (i.e. a recorded stroking is shown while the subject is being stroked totally differently). In the synchronous condition, the subject should ideally identify himself to the virtual character.

3.3 Experiment B : Swaying

This experiment invokes whole body movements thus adding a motor / agency component. The measurement methods were the same as for experiment A (see below for the description of the measurement methods), even if we discussed interesting other measurement methods that we did not test. The reason is obviously that keeping the same measurement method allows us to compare the relative degree of identification between the two experiments. The subject was asked to perform a simple and basic movement, swaying irregularly from left to right and vice versa. In the synchronous condition, the subject's movement was projected on the virtual character (without time delay) and in the asynchronous condition, a previously recorded motion of the virtual character was projected, similarly to experiment A.

3.4 Hypothesis

When the virtual character is stroked (exp A) or moves (exp B) synchronously (without time-lag) a higher degree of identification is expected to be measureable than in the case where the stroking / moving seen on the virtual character is asynchronous with respect to the subject. We also hypothesize that the identification / attribution is stronger when an active component (Experiment B) is involved. This condition should allow us to point out the importance of this self-agency inhibiting effect.

		Conditions	
		Synchrony (1)	Asynchrony (2)
Experiments	Somatosensory input (A)	**A1 / 1**	**A2 / 2**
	Body movement (B)	**B1 / 3**	**B2 / 4**

Figure 1: Listing of experiments and conditions

Subject No:	...carries out:				...in other words:			
1	A1	A2	B1	B2	1	2	3	4
2	A1	A2	B2	B1	1	2	4	3
3	A2	A1	B1	B2	2	1	3	4
4	A2	A1	B2	B1	2	1	4	3
5	B1	B2	A1	A2	3	4	1	2
6	B1	B2	A2	A1	3	4	2	1
7	B2	B1	A1	A2	4	3	1	2
8	B2	B1	A2	A1	4	3	2	1

Figure 2: Proceeding protocol for the first part. The different conditions correspond to the letters (A1, A2, B1, B2) are described in the Figure 1

Subject No:	…carries out:			
2	B2 – C	B1 – L	A2 – L	A1 – C
3	B2 – L	B1 – C	A1 – L	A2 – C
4	B1 – L	B2 – C	A1 – C	A2 – L
5	A1 – C	A2 – L	B2 – L	B1 – C
6	A2 – C	A1 – L	B2 – C	B1 – L
7	A1 – L	A2 – C	B1 – C	B2 – C
8	A2 – C	A1 – L	B1 – L	B2 – L

Figure 3: Proceeding protocol for the part with EDA measurement. Note that we could not measure the EDA for subject 1. The letters A1, A2, B1 and B2 are described in Figure 1. "L" corresponds to the falling of the lamp and "C" of the column.

4 Method and Experiments

4.1 Subjects

8 subjects, all students, right handed male or female (4 of each) between the age of 18 and 30 years, took part to the experiment. With these inclusion criteria we tried to exclude misleading results due to potential differences from education, ambidexterity and age.

All subjects were "naïve" to the exact aim of the study. The cover-story will be a qualitative test of immersion in a newly developed program of virtual reality. Cognitive Psychology was not mentioned at any time.

4.2 Material

4.2.1 Hardware

We used the ATC ReActor2 motion capture system, which consists of a network of infra-red light emitting markers and infra-red light sensing detectors contained in an open-sided rectangular frame made of aluminium extrusion. For more specific information please refer to reference [12].
We used screen retro-projection rather than HMD glasses.

In both experiments the subject wears a black "Velcro-suit" with 20 sensors attached to track his movements (the ReActor system detects the positions of all the sensors and sends it to the software). After doing some pre-tests on ourselves, we found that 20 sensors were sufficient for the needed movements of the character to seem natural. There was also a brush available with two additional sensors for experiment A.

EDA (Electro-Dermal Activity) has been measured with an EEG (Electro Encephalo Gram, Biosemi) system.

4.2.2 Software

ReActor FusionCORE software allowed us to treat the data collected by the motion capture system and send it to Motion Builder software. The Motion Builder software then created the 3D environment for the virtual character that was projected on the big screen.

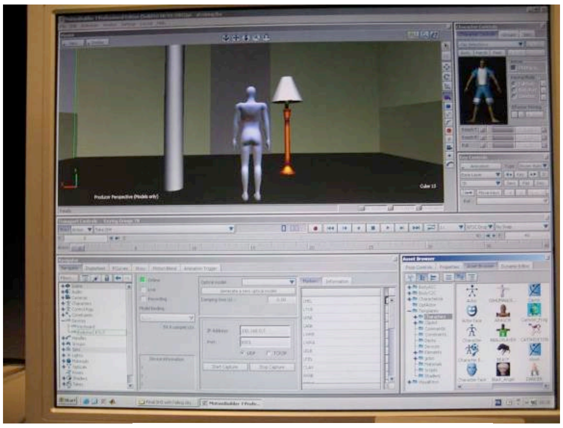

Photo 1. Motion builder software that was used. The room and character are the ones presented in our experiments

4.3 Experimental setup

First the subject had to be prepared. He had to put on the "Velcro-suit" and then all the sensors had to be placed on the subject. Then, the well working of all sensors had to be verified and we needed to ensure that everything was fine with the ReActor Systems. After that, the virtual body on the Motion Builder software could be rescaled to fit for each subject. Instructions about the experience were then given to the subject. During the experiments, the subjects also had to listen to an mp3 player playing some white noise, so that he/she was not disturbed by external noises.

4.4 Procedure

First, each subject got two documents to read, informing them that the experiments are not harmful and that no known long-term side effects are reported. A written consent from the subject to participate in the experiment was also asked. Second, a questionnaire to verify that they are really right handed people had to be filled out.

The experiences then began. We first did 3 control condition measurements for the shift (i.e. the subject was placed at a fixed position, then we asked him to close his eyes and moved him by 1 meter to the back, and then 1 meter to the right or the to the left. After that, we asked him to go back to where he thinks he initially was (eyes closed), and finally we measured where he went with respect to his initial position (more explanations about this displacement are given below).

Next we started with one of the condition (alternating the order for the different subjects, to avoid order effects, see figure 2). The experiment (one condition) lasted about 1 minute and was followed by a shift-measurement (see "Measurements" for explanations). This procedure was repeated for the three next experiments. After having accomplished the 4 conditions, we repeated three times a control shift measurement in order to see if the subject was reasonably constant or if he went back to totally arbitrary positions.

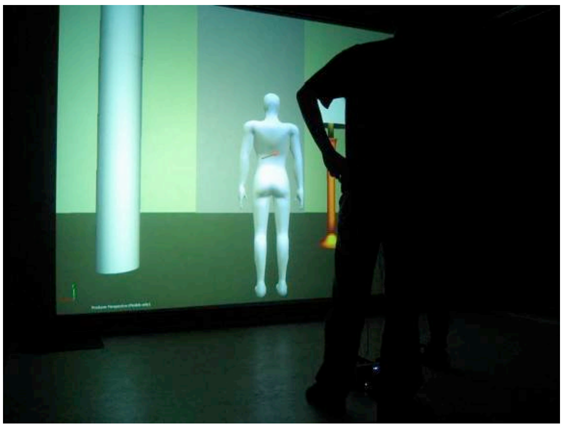

Photo 2. Subject being stroked and seeing the stroking on the screen.

Then the subject had to fill out questionnaires on these four experiments and once the questionnaires were filled out, we did again the four experiences in another order, to measure the fear response using the EDA (see below). No shift measurements were performed this time (see figure 3 for the order of these conditions). Finally, personality questionnaire had to be filled out.

The complete experiment took about 1h15 to 1h45 minutes.

4.5 Measurements

4.5.1 Shift measurement

According to the Triangle Path Completion (TPC) the subject was moved 1 meter to the back and then 1 meter to the right or the left, doing small steps in order to prevent the subject from keeping track of the displacement. He then had to go back to where he thought his initial position was (eyes closed). We then measured the shift between his position and the original one (separately in the left-right and back-forward directions). The hypothesis is that if the illusion is present, the subject should feel attracted to the virtual character and a forward shift should be present (the projected character will be right in front of him, so there should moreover not be any left-right shift).

4.5.2 EDA measurement (fear reaction)

To have more means to measure the intensity of the illusion, a second part of the experiment has been to repeat the same conditions, with a different measurement method. EDA (also known as **g**alvanic **s**kin **r**esponse) is a method to measure the electrical resistance of the skin. This measure has been used to detect a higher activity of the sweat glands, produced by any emotion. Two captors are set on one side of the hand, on specific points corresponding to yellow and red zones (see figure 4) and a second pair of captor is set on the other, at less specific places, as control signal.

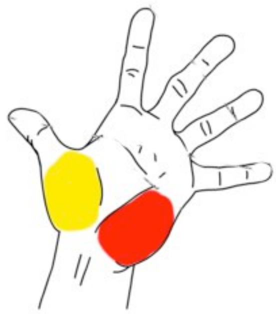

Figure 4: the position of the captors for the EDA

In this part we therefore observed the subject's fear response in the following way: after 1 minute of the experiment, a virtual object that was already present on the screen suddenly fell on the subject. We programmed two such objects: a standing lamp and a column, and used alternatively the falling of the one or the other. We recorded the subject's electro-dermal activity in order to obtain an intensity measure of his fear response.

The hypothesis here is that if the illusion is present, the subject, identifying himself to the VR character, should be more afraid than if there is no illusion, i.e. we should detect a greater effect in the synchronous condition than the asynchronous one.

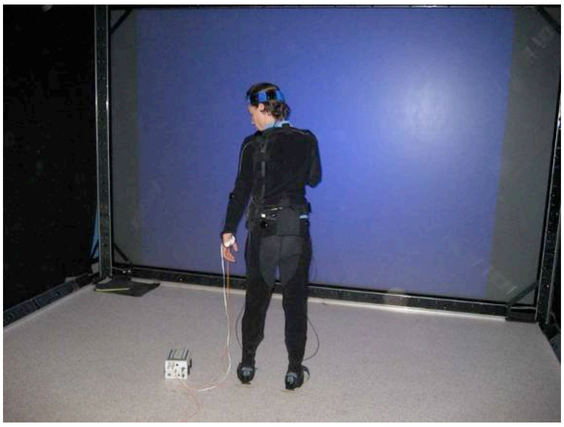

Photo 3. The subject is ready for the EDA measurement.

4.6 Questionnaires

After the first series of experiments followed by the shift measurements, the subjects filled out a first set of questionnaires, one for each condition, in order to obtain information about the subject's feelings during the experiments. The questionnaires were quite similar to the ones used by Bigna Lenggenhager in preceding preparatory experiments.

In this first set of questionnaires, the subjects were asked to remember the four situations and answer according to the feelings they had during each one of them, indicating first the intensity of the described feeling on a scale from 0 to 100 with an interval of 10, and secondly indicating if this felt intensity was present during the whole part of the experiment (one condition) or not, similarly indicating the percentage on a time scale from 0 to 100 with an interval of 10. To give an example, a question could be answered saying: "Yes I felt the suggested feeling as it is written in question number # with an intensity of 80, but I only felt it towards the end, let's say in the last third of the two minutes lasting experiment." So they would have indicated the latter statement with 30 points on the time scale. For all questionnaires, there was a "free comments" section given at the end, so that they could express themselves on strange feelings that they possibly experienced and which would not have been addressed within the questions.

Finally, after measuring EDA, a last set of questionnaires about the subject's personality had to be filled out. These two additional questionnaires which are commonly used in clinical tests are called "Perceptual Aberration Scale" (PAS) questionnaire and "Dissociative Identity Scale" (DIS) questionnaire respectively.

These last questionnaires permitted to know if subjects had particularities that could influence on our experiments and to check it if they had really different results comparing to the other subjects.

In order to determine whether our subjects were "normal subjects" we had them fill out the PAS questionnaire, which measures the subject's perceptual skills or, more precisely, the aberrations of their perceptual skills compared to established norms. These norms are based on the Chapman et al. Psychosis-Proneness Scales for Caucasian undergraduate students in Introductory Psychology courses at the University of Wisconsin-Madison [13]. Jean and Loren Chapman and their students gathered these norms and the item-data (reported on each scale) on their NIMH – supported research project at the University of Wisconsin-Madison in the 1980's. Their tables provide separate norms for males and females.

All questionnaires as well as the handed out information sheet are given in the appendix.

4.7 Protocol / Scripts (Summary of the procedure)

We precisely described each experience to the subjects with the same explanation to be sure to have no inequalities in the results due to mismatches in the explanation of the execution of the experience.

In order to keep the subjects as naïve as possible throughout the experiences, we avoided to tell them about the ultimate goal of the study. Cognitive psychology was never mentioned. We focused our explanations on software synchronization process developments for virtual reality studies. As soon as the subject arrived, he or she was given the info-and written consent sheet and the right-hander questionnaire. We started then to dress up the subject, calibrated the sensors and got the software ready. As this process was new and quite interesting for the subjects, they did not really have the time to think about asking questions about the experience which could have brought us into annoying situations…

The subject was then taught about the displacement procedure: as soon as the sequences on the screen were finished they should close their eyes and begin to make small steps in place. Then they would be guided in the displacement by having us taking them by the shoulders. And after letting them go, they should try to go back to the same location as they initially were.

They were then told that, in order to see how this should work, we should first train the displacement procedure three times. Having done these three control displacements, they were taught about the task for the following 1 to 2 minutes lasting sequence, which was either the stroking or the swaying task. For each condition they were asked to focus their concentration on what was happening on the screen and their feeling about it. After the experiments we asked them to repeat the displacement measure three more times in order to detect any changes. They were then invited to fill out the first set of questionnaires, before going on with the same four experiments without displacement, but with EDA measurements.

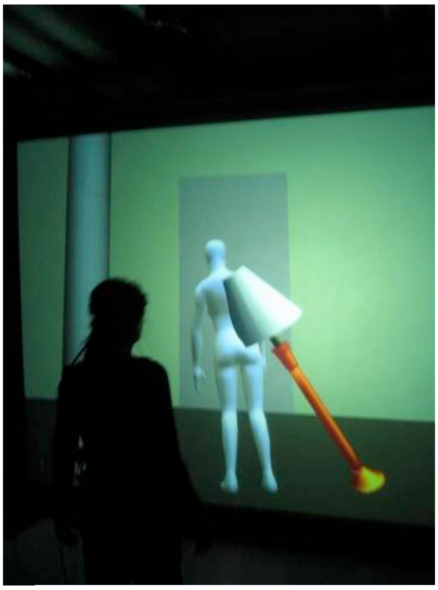

Photo 4. The lamp has suddenly fallen on the subject to measure his fear reaction.

5 Results

5.1 Shift

After collecting the results from the shifts of the subjects, the values have been averaged in order to continue the analysis of the data.

We first checked that the subjects did not get better at replacement along trials; the three controls before and after the experience did not lead to a significant difference ($p > 0.5$). This allowed us to use the average of the control shifts as general control condition and use them as reference for our statistical tests.

In our study, we were most interested in the results about anterior shift; however the data on lateral shift also yielded some interesting results. It can be seen on the histograms with the individual data (figures 5 and 6) that most of the subjects (1,2,4,6,7,8) experienced an anterior effect during the synchronous stroke condition but not during the asynchronous condition. Surprisingly most subjects showed an opposite effect during the swaying condition.

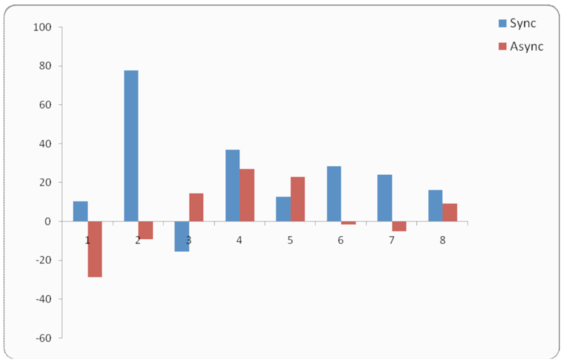

Figure 5: Relative displacement for stroking.

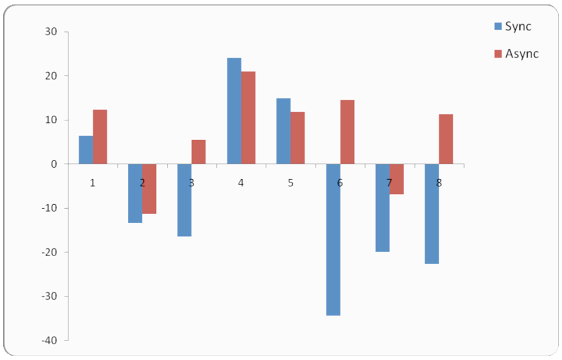

Figure 6: Relative displacement for swaying.

A 2x2 ANOVA with the within subjects factors ([stroking/swaying] VS [sync/async]) revealed a significant interaction effect between the two conditions (p-value: 0.033). This allowed us to do the following dependant sample t-tests.

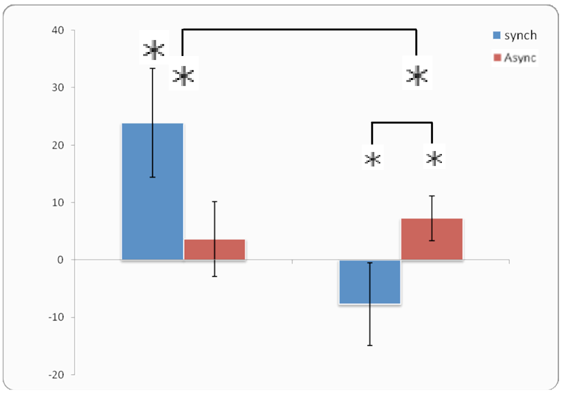

Figure 7: Average shift for stroking and swaying.

We can clearly see on the averaged histograms (figure 7) a strong difference of means between the synchronous and asynchronous stroke and also between the synchronous stroke and sway. Dependent t-tests demonstrated a significant difference between the synchronous stroking and swaying conditions. This was not the expected results but this is still really interesting and will be further studied in the discussion section. Concerning asynchronous and synchronous stroke, the t-test showed no significant difference (p-value: 0.148). The t-test also surprisingly showed an almost significant difference between the synchronous and asynchronous swaying condition (p-value: 0.058)
We also did a one sample t-test (against 0, which is in our case the motor control condition as we are using the relative shifts). We obtained as expected a significant effect of the synchronous stroke condition (p-value: 0.039).

We also looked at the lateral shift for the control conditions. We remarked that in the longitudinal control displacement, the subjects showed a negative mean. Meaning that instead of stopping at their initial point, they were stopping 16.61 cm before it. We wanted to determine if this shift was reproduced in the lateral displacement. So we averaged the left and right control conditions separately (remember that the subjects were displaced from 1 meter backward and 1 meter left or right). We obtained the expected results; when they were displaced to the left, they stopped 15.96 cm before the initial point and 17.875 cm when they were displaced to the right. We can see this displacement graphically on the figure 8.

We effectuated t-tests to see if the difference between left and right displacement was really significant and a significant effect was indeed seen (p-value: 0.045). This drift is really interesting and is also concordant with the results Bigna Lenggenhager obtained in her experience.

We also noticed a curious effect; during the experiment, the subjects experienced an 8 cm right shift, meaning that, in average, they went back 8 cm more right than the initial starting point. This should have been equilibrated by the alternate left/right displacements but it did not. We ran a one sample t-test against the 0 motor control condition and obtained a significant effect (p-value: 0.044). This is interesting as Bigna Lenggenhager noticed the same right shift during both of her experience and did not find any clear explanation. Some hypothesis will be discussed in the discussion section.

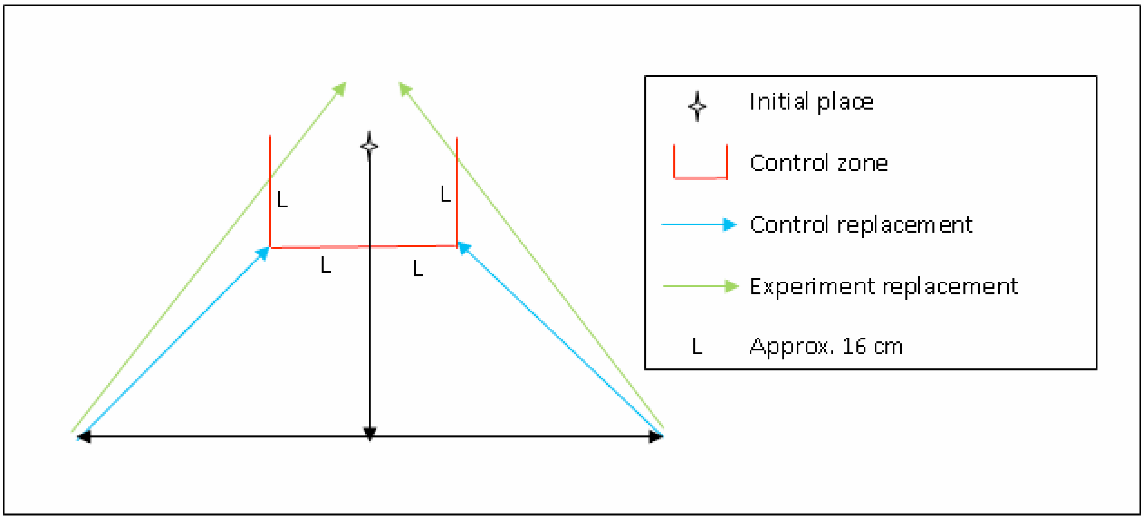

Figure 8: Displacement of the subjects: the subjects usually come back to their initial point out of the red zone during control and go in this zone and further during experiments.

5.2 EDA

For the EDA measurement, we obtained the curves shown in Figure 9 and 11. Given that the EDA method returns the resistance of the skin, the plots here represent the inverse value of EDA, the conductance (in Siemens).

The analyses done on those plots are mainly visual. The first global observation which can be done is the higher variability on the whole signal of the swaying condition compared to the stroking condition. This is due to the reactivity of the EDA system to the movements of the subject (which leads to this "wave appearance" on the second figure). Considering this, fewer observations are naturally done on the swaying condition, which can only show a trend, mainly with subjects 1, 2 and 6.

In the stroking condition, subjects 1, 2 and 5 appear to have the desired trend – a reaction just after the fall of the object. This difference is about $2*10^{-7}$ Siemens and looking at the mentioned subjects in the swaying condition shows that this value is also approximately the same.

Given the very low difference of values in our experiment, no conclusion can really directly be made about the reaction of the subjects. Nevertheless, we believe that this perceptually observable difference indicates that something effectively happened, but has surely been decreased by different factors that appeared in our procedure.

In addition to the movement in the swaying condition, another source of noise in our data could be an effect that we observed for the different subjects; some of them happened to laugh during one or another condition, which shows that the subjects were maybe not sufficiently immersed in the scene, and maybe that the presence of an experimenter next to him during the stroking increased this.

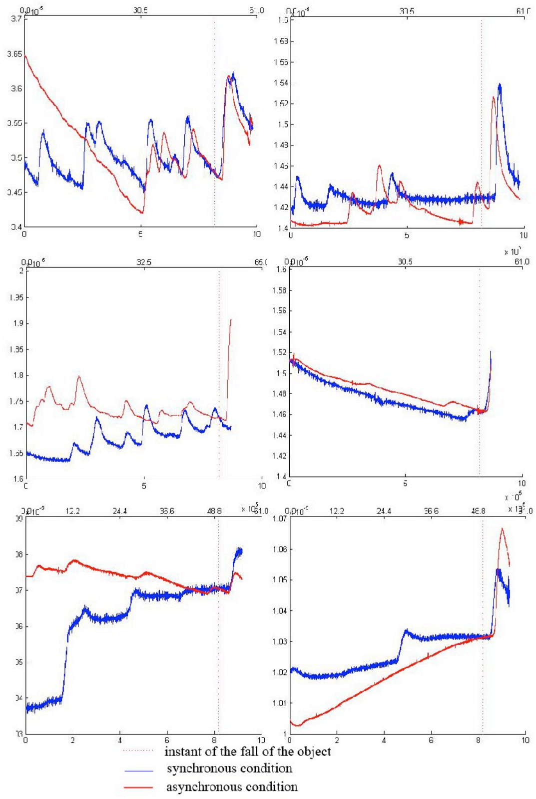

Figure 9: EDA recording per subject in the stroking condition

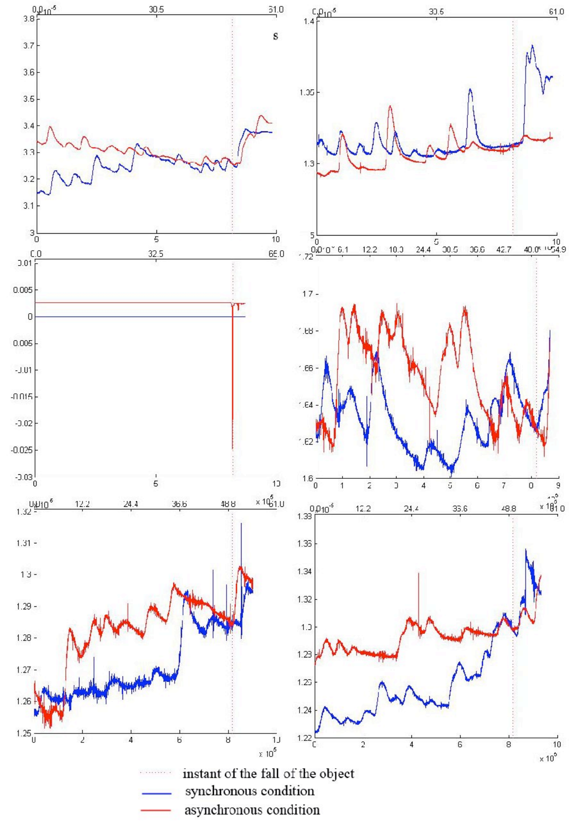

Figure 11: EDA recording per subject in the swaying condition

The figures above confirmed a trend towards our hypothesis and we needed some more analysis. An ANOVA has been done for the signals normalized for each subject and we got the figure 10, showing the same effects, mainly in the swaying condition (Note: one subject is missing in asynchronous swaying condition due to a problem with the EDA measurements). These results were confirmed by the average of these values, shown in figure 12. The final results showed a significant effect only in swaying condition between synchronous and asynchronous condition.

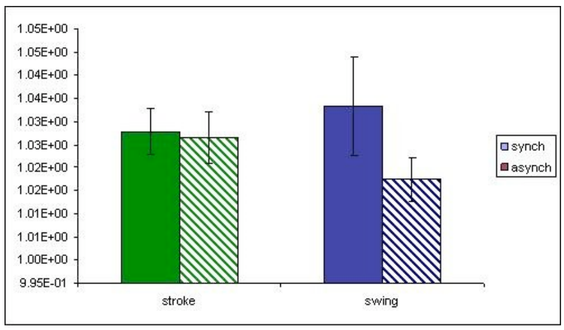

Figure 12: Average of the normalized signal values

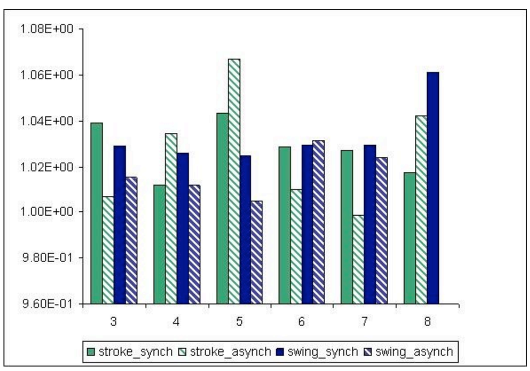

Figure 10: Normalized EDA signal for each subject after falling of the object

5.3 Questionnaires

5.3.1 Questionnaires 1-4:

On figure 13, four histograms of the mean and weighted mean intensities according to the described feelings for each question are represented. Each graph compares the synchronous versus the asynchronous condition. The weighted means were calculated taking the time scale value as weighting coefficients, and thus multiplying the latter with the intensity values. The error bars (standard deviations) are of course symmetric. For graphical simplicity only the upper part of the error bar is shown.

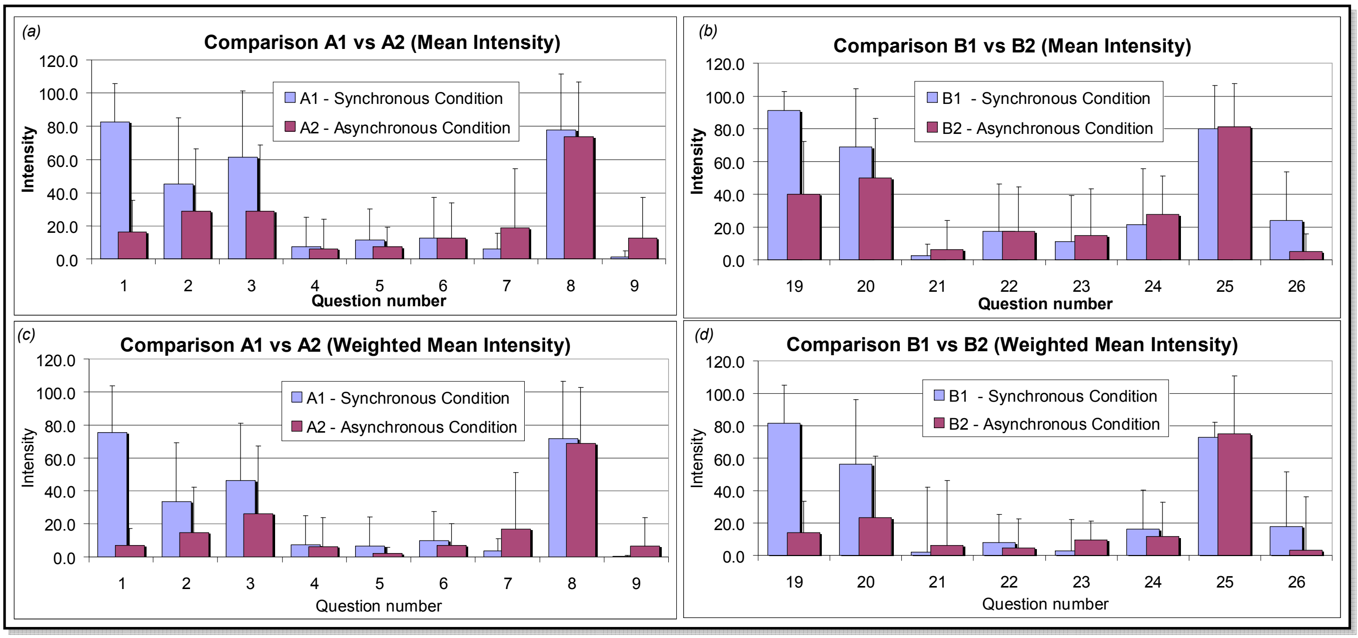

Figure 13: Histograms of the mean and weighted mean intensities according to the described feelings for each question.

Questions 1 to 9, and 19 to 26 were the following (French version only):

Durant l'expérience, il y a eu certaines fois où:

1	Il m'a semblé que je sentais le toucher du bâton à l'emplacement où je regardais le corps virtuel en train d'être touché.
2	Il m'a semblé que le toucher que je sentais était dû au bâton touchant le corps virtuel.
3	J'ai eu l'impression que le corps virtuel était mon propre corps.
4	Il m'a semblé que ma conception des couleurs changeait au cours de l'expérience.
5	J'ai eu l'impression que mon corps (réel) se déplaçait (comme aspiré) vers l'avant (en direction du corps virtuel).
6	Il m'a semblé avoir plus d'un corps.
7	Il m'a semblé que le toucher que je sentais venait de quelque part entre mon propre corps et le corps virtuel.
8	J'ai eu l'impression que la taille du corps virtuel correspondait approximativement à la mienne.
9	Il semblait que le corps virtuel se déplaçait (comme aspiré) vers l'arrière (en direction de mon corps).

19	Il m'a semblé que les mouvements que le corps virtuel exécutait étaient mes mouvements.
20	J'ai eu l'impression que le corps virtuel était mon propre corps.
21	Il m'a semblé que ma conception des couleurs changeait au cours de l'expérience.
22	J'ai eu l'impression que mon corps (réel) se déplaçait (comme aspiré) vers l'avant (en direction du corps virtuel).
23	Il m'a semblé avoir plus d'un corps.
24	Il m'a semblé percevoir mes mouvements quelque part entre mon propre corps et le corps virtuel.
25	J'ai eu l'impression que la taille du corps virtuel correspondait approximativement à la mienne.
26	Il me semblait que le corps virtuel se déplaçait (comme aspiré) vers l'arrière (en direction de mon corps).

Of the above questions, number 1-3 and 19-20 were most interesting to test our main hypothesis, meaning that they represent most the potential effects that we wanted to observe. Note that these are the questions (modified) according to our experience that Botvinick [5] found to be positively answered.

5.3.1.1 Stroking (A1, A2):

We can clearly see that there is an effect that goes in the direction of our assumption, namely that the subjects identify themselves more with the virtual character in the synchronous condition than in the asynchronous one (graph (a), Q 1-3). But only question 1 is actually significant (paired Student test, $p<0.05$). Question number 3 shows a trend ($p<0.1$). This might mainly be due to the small number of subjects tested. Nevertheless, being the "strongest" question in the sense of our hypothesis, question number 3 visibly shows that if there was a forwards shift measured, it would most possibly be due to a confusion of the subject's sense of ownership. Furthermore, it is interesting to note that there was a difference (trend, $p<0.1$) between male and female subjects for this question. In the synchronous condition, the mean intensity of female subjects was much higher than the male subject's mean intensity, whereas in the asynchronous condition we observed the opposite pattern.

Questions 4 and 8 were control questions, where we expected a small score for question 4 but a high score for question 8, both without difference between synchronous and asynchronous condition. The subject's answers did clearly match our expectations for the stroking as well as for the swaying task.

5.3.1.2 Swaying (B1, B2):

We get a significant difference ($p<0.05$) for the synchronous versus the asynchronous condition for question number 19, which states that the subjects did clearly distinguish between a character performing the subject's movements and a character that did not. Question 20 also shows a trend ($p<0.1$) but only when the intensity values are weighted. However, this means that the subjects did identify themselves more with the virtual character in the synchronous condition than in the asynchronous condition. Similarly to the stroking task and the difference between male and female subjects, the swaying task showed again a large disparity between male and female subject's feelings on question 20, but this time male subject's showed up to identify themselves quite stronger to the virtual character than did female subjects. If yes or no this observation yields an intrinsic difference in the sense of ownership or sense of agency between male and female subjects according to the nature of the task to fulfil, might be worthy to investigate more profoundly in further studies.

Questions 21 and 25 were again control questions and as before, they do not show any difference as expected.

Note that question number 26 (equivalent to question number 9) did show a slight (not significant) difference for the swaying task. Indeed we observed that some subjects had the tendency to slightly step forwards while doing the swaying, i.e. while changing from one foot to the other. Whether it was the feeling of being aspired forwards which made them actually step forwards or it was the fact that they stepped forwards which made them feel as if they were aspired forwards, we unfortunately cannot report. Yet, the fact that they were stepping forward during the experiment was something we could hardly control and which made measurements more difficult, and future experiments should therefore take into account such side effects and try to avoid it.

5.3.2 Questionnaire 5 - The Perceptual Aberreation Scale (PAS)

On figure 14 the PAS scores are given. The first two columns provide the data for males and the third and fourth columns provide the same data for females. The p data were obtained from college students enrolled in the introductory psychology classes at the University of Wisconsin-Madison. The fields are coloured whenever our scores are higher than the Chapman means for each question individually.

Males		Females		Total				
n = 775	n = 4	n = 840	n = 4	N = 1615	N = 8			
p	p	p	p	p	p			
0.22	0.00	0.17	0.00	0.19	0.00	T	1	Sometimes I have had feelings that I am united with an object near me.
0.20	0.00	0.25	0.50	0.23	0.25	T	2	I have sometimes had the feeling that one of my arms or legs is disconnected from the rest of my body.
0.10	0.00	0.16	0.00	0.13	0.00	T	3	I sometimes have to touch myself to make sure I'm still there.
0.23	0.25	0.17	0.25	0.20	0.25	T	4	Sometimes part of my body has seemed smaller than it usually is.
0.15	0.00	0.17	0.00	0.16	0.00	T	5	At times I have wondered if my body was really my own.
0.20	0.00	0.19	0.25	0.19	0.13	T	6	Parts of my body occasionally seem dead or unreal.
0.11	0.00	0.09	0.00	0.10	0.00	T	7	Sometimes I have had a passing thought that some part of my body was rotting away.
0.10	0.00	0.10	0.00	0.10	0.00	T	8	Occasionally I have felt as though my body did not exist.
0.05	0.00	0.03	0.25	0.04	0.13	T	9	Sometimes I have felt that I could not distinguish my body from other objects around me.
0.18	0.25	0.15	0.25	0.16	0.25	T	10	It has seemed at times as if my body was melting into my surroundings.
0.38	0.25	0.34	0.50	0.36	0.38	F	11	I have never felt that my arms or legs have momentarily grown in size.
0.30	0.25	0.31	0.25	0.31	0.25	F	12	The boundaries of my body always seem clear.
0.09	0.00	0.06	0.00	0.07	0.00	T	13	I can remember when it seemed as though one of my limbs took on an unusual shape.
0.30	0.25	0.32	0.25	0.31	0.25	T	14	I sometimes have had the feeling that my body is abnormal.
0.14	0.00	0.14	0.25	0.14	0.13	T	15	I have sometimes had the feeling that my body is decaying inside.
0.07	0.00	0.04	0.25	0.05	0.13	T	16	I have had the momentary feeling that the things I touch remain attached to my body.
0.08	0.00	0.08	0.25	0.08	0.13	T	17	Occasionally it has seemed as if my body had taken on the appearance of another person's body.
0.28	0.25	0.22	0.50	0.25	0.38	T	18	Sometimes I feel like everything around me is tilting.
0.11	0.00	0.09	0.50	0.10	0.25	T	19	Ordinary colors sometimes seem much too bright to me.
0.20	0.00	0.17	0.25	0.18	0.13	F	20	My hands or feet have never seemed far away.
0.09	0.00	0.09	0.50	0.09	0.25	T	21	I have sometimes felt that some part of my body no longer belongs to me.
0.10	0.00	0.08	0.00	0.09	0.00	T	22	I have felt that something outside my body was a part of my body.
0.21	0.25	0.26	0.25	0.24	0.25	T	23	I have felt that my body and another person's body were one and the same.
0.49	0.25	0.54	0.75	0.52	0.50	T	24	Now and then, when I look in the mirror, my face seems quite different than usual.
0.06	0.00	0.06	0.00	0.06	0.00	T	25	I have felt as though my head or limbs were somehow not my own.
0.22	0.25	0.17	0.25	0.19	0.25	T	26	Sometimes when I look at things like tables and chairs, they seem strange.
0.27	0.25	0.20	0.25	0.23	0.25	F	27	I have never had the passing feeling that my arms or legs have become longer than usual.
0.05	0.00	0.05	0.00	0.05	0.00	T	28	I sometimes have had the feeling that some parts of my body are not attached to the same person.

Figure 14: On each list of items, p = the proportion of subjects who answered in the keyed direction, that is, in the direction of a high, or pathological sense; p = idem for our eight subjects (every second column). The T or F by each item indicates whether a True or False answer is in the pathological direction.

On figure 15 a histogram comparing overall mean scores is shown. Obviously our male subjects have a lower perceptual aberration mean than norm. However, due to the small number of subjects we cannot say anything about statistical significance.

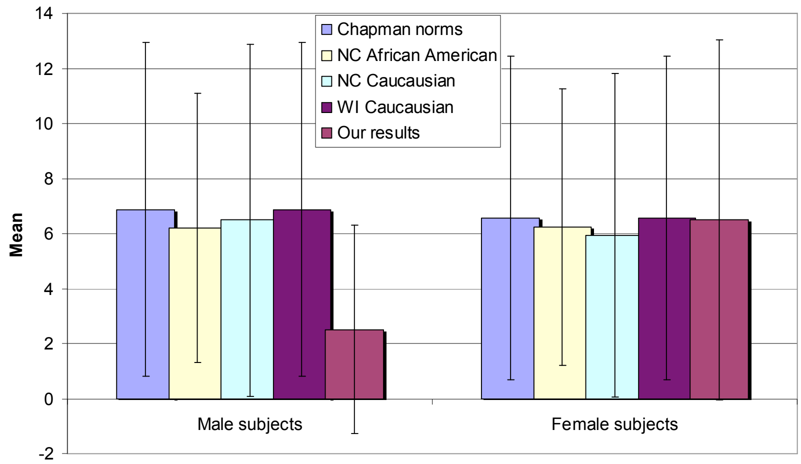

Figure 15: Perceptual Aberration Scale. Comparison to Chapman norm values. Error bars represent standard deviations. NC African American = norms based upon African American college students at the University of North Carolina at Greensboro, Winston-Salem State University, and North Carolina A&T State University. NC Caucasian = norms based upon Caucasian college students at the University of North Carolina at Greensboro. WI Caucasian = norms based upon Caucasian college students at the University of Wisconsin-Madison.

All norm values do exclude about 19 "cutoff scores", scores which are 1.96 standard deviations above the mean. Subjects are considered deviant on a particular measure if their score is equal to or greater than the cutoff score. There are no cutoff scores within our subject's scores. Yet, since scores may vary with age, SES, and ethnicity, the applicability of these norms should be considered carefully.

5.3.3 *Questionnaire 6 – Dissociative Identity Scale (DIS)*

The last questionnaire enables us to compare Dissociative Identity Disorder (DID) scores of our subjects with norm values from dissociative experience scale scores in the general population in the city of Winnipeg, Canada. The higher the DES score, the more likely it is that the person suffers from DID. In a sample of 1'051 clinical subjects, however, only 17% of those scoring above 30 on the DES actually had DID. In most studies the average DES score for a DID positive patient is in the 40s, and the standard deviation about 20, roughly about 15% of clinically diagnosed DID patients score below 20 on the DES. It has been shown that the DES can actually predict who will not, and who may have a dissociative disorder with high accuracy. The average DES score usually lies between 10.0 and 20.0.

In figure 16 the individual and mean DIS scores of our subjects, as well as the "DID positive" threshold value are represented. We observe an overall mean score of 20, which is representative for general population. However, this mean score has been achieved with quite disparate individual scores, meaning that 3 subjects had rather very low scores (below 5) and two other subjects had rather high scores (above 35).

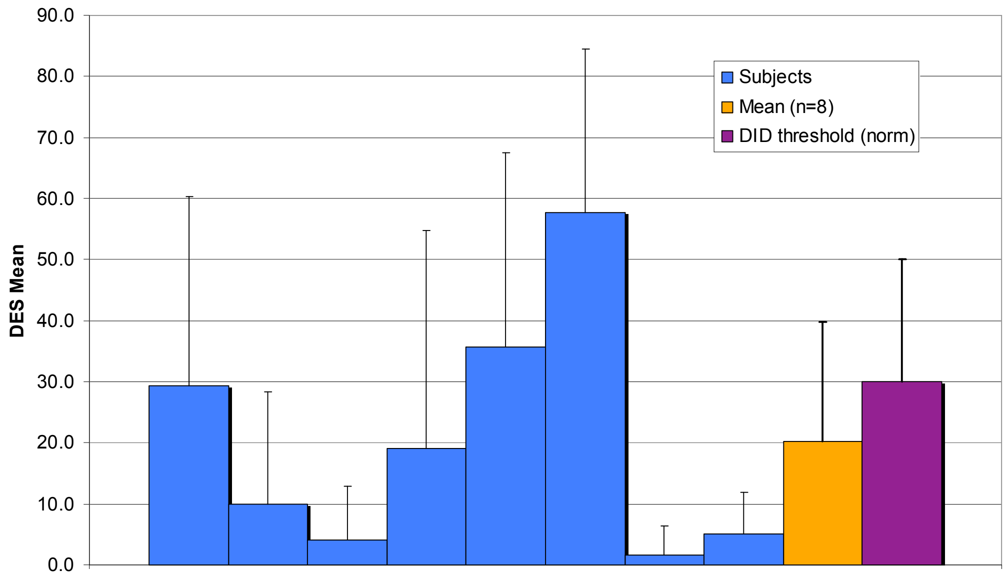

Figure 16: DID scores for 8 subjects. Only the upper part of the error bars is shown.

The distribution of "dissociative experiences" in the general population closely resembles that in college students, except that students are younger and do not manifest the slight decline in DES score that occurs with age; the findings are consistent across many studies and in a variety of different cultures and languages. In general, most people do not report any pathological dissociative experiences. Moreover, many dissociative experiences are normal and benign, and extrapolations from self-report data set the lifetime prevalence of dissociative disorders in the general population in the range of 2% to 11%.

The items in figure 17 are ranked from the highest to the lowest average score: the possible score for each item ranges from 0 to 100, depending on how frequently one has the given experience. The overall DES score is the sum of the 28-item scores divided by 28, and therefore also ranges from 0 to 100. The second and fifth column are the frequency of endorsement of each item, or the prevalence: This is the percentage of respondents scoring above zero for that item. The third and sixth column is the percentage of respondents who experience this item with a score above 30: This threshold value of

30 has been chosen because it is regarded as a threshold score for the pathological range by many investigators. The full questionnaire is given in the annexe.

Dissociative Experience Scale Scores in the General Population in the City of Winnipeg, Canada				***Rubber Body Illusion Experiment***		
(N = 1,055)				***(N = 8)***		
Item	**Mean Score**	**Prevalence %**	**Subjects Scoring > 30 (%)**	**Mean Score**	**Prevalence %**	**Subjects Scoring > 30 (%)**
Able to ignore pain	25.6	74.7	33.4	17.5	50.0	25.0
Missing part of a conversation	24.3	83.0	29.0	48.8	100.0	62.5
Usually difficult things can be done with ease and spontaneity	22.8	73.1	28.4	30.0	75.0	50.0
Not sure whether one has done something or only thought about it	21.2	73.1	24.7	41.3	75.0	50.0
Absorption in television program or movie	20.2	63.9	24.2	38.8	75.0	50.0
Remembering past so vividly one seems to be reliving it	17.4	60.4	19.2	37.5	75.0	37.5
Staring into space	15.3	62.6	25.7	36.3	87.5	50.0
Talking out loud to oneself when alone	15.2	55.6	17.7	18.8	50.0	25.0
Finding evidence of having done things one can't remember doing	13.5	58.4	14.3	27.5	37.5	37.5
Not sure if remembered event happened or was a dream	12.6	54.6	12.5	46.3	87.5	62.5
Being approached by people one doesn't know who call one by a different name	12.2	52.4	4.1	8.8	12.5	12.5
Feeling as though one were two different people	11.5	47.0	11.8	18.8	25.0	25.0
So involved in fantasy that it seems real	10.0	44.5	10.9	23.8	62.5	25.0
Driving a car and realizing one doesn't remember part of the trip	9.0	47.8	7.5	37.5	62.5	50.0
Not remembering important events in one's life	8.8	37.9	9.5	16.3	37.5	12.5
Being in a familiar place but finding it unfamiliar	8.6	40.0	8.2	15.0	37.5	25.0
Being accused of lying when one is telling the truth	7.3	40.8	6.0	7.5	25.0	0.0
Finding notes or drawings that one must have done but doesn't remember doing	6.7	34.0	6.3	13.8	37.5	25.0
Seeing oneself as if looking at another person	5.3	28.6	4.3	6.3	25.0	0.0
Hearing voices inside one's head	5.3	26.0	7.3	3.8	25.0	0.0
Not recognizing friends or family members	5.1	25.8	4.6	12.5	25.0	12.5
Other people and objects do not seem real	4.9	26.3	4.1	7.5	25.0	12.5
Looking at the world through a fog	4.7	26.3	4.0	7.5	12.5	12.5
Finding unfamiliar things among one's belongings	4.5	22.1	4.1	11.3	12.5	12.5
Feeling as though one's body is not one's own	3.9	22.7	3.6	2.5	12.5	0.0
Finding oneself in a place but unaware of how one got there	2.8	18.8	2.0	16.3	37.5	12.5
Finding oneself dressed in clothes one doesn't remember putting on	1.9	14.6	1.4	11.3	12.5	12.5
Not recognizing one's reflection in a mirror	1.8	13.6	1.2	18.8	25.0	25.0

Figure 17: DES score comparison. Orange (darker) coloured fields are scores that are 20% or more above the mean values from DES scores from the city of Winnipeg, Canada (N=1055).

6 Discussion

For the swaying condition, an interesting effect emerged from the data: some subjects try to synchronize themselves with the virtual body in asynchronous condition. So we think that it is possible that the subjects have more illusions when they concentrate them to be synchronous with the subject, than in the synchronous condition where they have nothing to do to be synchronous with the subject! That is probably why the results for the swaying condition are inversed compared to the stroke condition. One subject reported in the "free comments" section of the questionnaire, that he had the impression of seeing his body, but just delayed in time. For this subject the illusion was, as a matter of fact, present in the asynchronous condition. Another subject reported for this same condition (B2) that, in effect, he felt a tendency of "wanting to compensate" between the movements on screen and his own.

As we had only 8 subjects due to the limited time frame of the study, we did not find any general significant result for the shift difference measurement as we expected. But the results obtained tends to show that increasing the number of subjects, thus diminishing the standard deviation, should probably yield significant results. However we found a significant anterior shift during the synchronous stroking condition, replicating results obtained in Bigna Lenggenhager experiment.

Another interesting result is the lateral shift obtained in the control condition and during experiments. Concerning the shift obtained during the control condition, other VR experiments about homing demonstrated the same undershoot pattern [14]. However the more interesting is the right shift obtained during the experiments. This may be due to the fact that subjects were all right-handed or due to a right orientation of the virtual character (less probable); however this cannot be due to undershoot because of the balanced left and right displacement. As we could not find any clear explanation, this should be further studied next experiments.

If we compare our shift results with the questionnaire, it seems that our hypothesis about the illusion is not false. The subjects felt, in some aspect, kind of an association with the virtual body. But this feeling was more on technical questions as the one that "the stroking was in the same place on his back and on the virtual body's back" or as "the swaying of the virtual character was the same as his swaying", rather than that the subject felt the actual illusion of a real association of his body with the virtual character. However, some questions about the body illusion show a slight difference, and associating it with our conclusion about the shift result, it is possible that an improved setup of our experiments and a higher number of subjects might yield some significant results for the body illusion. At least we can say that we do observe a clear trend, but which unfortunately is not significant.

We think that for this experiment the image of the virtual body was really missing of details that could have helped the subjects to identify himself to his virtual body. For example, the virtual character was not always well scaled to the subject's size, resulting in distortions in the virtual body and its movements (trouble with position of head and shoulders). Moreover, we sometimes had a short delay (due to the computer) between the swaying of the subject and the swaying of the virtual body in the synchronous condition. Furthermore, the projection of the body was not always on the right height for some subjects in the asynchronous condition, since for this condition the image of the virtual body was pre-recoreded. For the stroke conditions, the virtual body was not moving at all, because we could not detect the sensors of the subject and the ones of the stroking object at the same time.

Further more, we decided to use a screen projection instead of virtual reality glasses because the representation of the virtual body looked really better and the size of the body was better respected when looking on the screen projection even if there would have been other advantages with the glasses. For example, we think that the presence of surrounding steady objects such as the detector bars of the tracking cage, or even the walls might serve as a reference for the subject. This reference effect might compete with the self-identification effect to the virtual character and thus could influence on the measured shift. However, it seems that when subjects are well concentrated on the screen, these factors do not interfere too much. Also, using the screen, only a "projected 3-dimension" could be achieved which can be inhibiting for the effect we were looking for; but the VR-glasses to our disposal also only delivered 2d images.

Improving all these details could lead to truly better projection of the virtual body and could help the subject to have a more intense body illusion.

Concerning the questionnaires, they were filled out only after the four conditions and not after each experiment individually, which may have resulted in a loss of the subject's memory according to his feelings or in mixing up the feelings present during the four conditions. Yet, since the questionnaires enquire on cognitive and self-sensational effects, this was a piece of information that we tried to obstruct at any price, as giving the questionnaires at the end of each part might have provoked a loss in the subject's naivety.

7 Conclusion

In this study we try to reproduce the rubber hand illusion to the whole body. This has been done with a quite complex experimental setup using a system of sensors for virtual reality and electro-dermal activity system.

We speculate that if we stroke the back of the subject while the subject sees a representation of himself, as it was done for the rubber hand illusion, the subject would also experience the illusion but for the whole body. We also speculate that this type of illusion could appear when the subject sways his own body and sees a virtual projection of himself.

The results were not completely significant but we had some trouble with the virtual body which did not look sufficiently realistic. Furthermore, we did not test enough subjects (due to the limited time frame for this study) in order to have a statistically relevant sample. For this reason, we conclude that this experiment is promising to give significant results with an improved and revised setup.

For further research, improving this experiment with a mechanical stroking machine could help to set the time delay so the range is for example [-100ms; 100ms] and the strokes sometimes happen before and sometimes after. It could be more efficient for asynchronicity.

Additionally it could also be interesting to have schizophrenia patients as subjects. The schizophrenic patients are already known for having "problems with self", it could be then interesting to conduct the same experience with such kind of subjects. Same for Cannabis addicts subjects which are also known for having self "alienation" (a lot of articles recently discussed about schizophrenia and cannabis relation [15]). We think these topics could be interesting for further experiments.

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