

Exploring the Feeling of Ownership over a Virtual Arm

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ABSTRACT

The “rubber hand illusion” allows the study of the mechanisms that support multisensory integration and self-representation of the own body image. In previous studies, we have shown that the incorporation of virtual parts to our body image by means of a correct multisensory stimulation is a versatile tool for the study of the self-body image generation. In this paper, we invoke the “virtual hand illusion” in a virtual environment using two alternating air puffs, which stimulate the back of both the virtual and the subject’s hand synchronously. The questionnaire results reflect an incorporation of the virtual arm to the own body image. Further, a correlation between the increase of muscle activity during the movement of the virtual arm and the mean score of the illusion-related questions was observed. These findings not only confirm that there was a degree of feeling of ownership over the virtual arm, but also suggest that the “virtual hand illusion” also engages and deceives the motor system.

General Terms

Experimentation.

Keywords

Computer Simulation, Human Body, Perception, Virtual Reality.

1. INTRODUCTION

The perception of our own body image is a fundamental aspect of how we experience ourselves. The self-representation of our body image results from a multisensory integration of different modalities (e.g.. visual, tactile, proprioceptive). Although body image seems to be highly stable, there is evidence that demonstrates that in fact our body image is malleable. The mechanisms that support multisensory integration and self-representation of the own body image have been extensively studied in real environments using a rubber arm [1,2], a mirrored representation [3] or a video projection of the arm [4].

With the “rubber hand illusion”, in which tactile sensations are referred to an alien limb, Botvinick and Cohen showed that synchronous stimulation of the hand of a rubber arm and the subject’s hidden real arm could result in a projection of ownership towards the rubber hand [1]. Therefore, the “rubber hand illusion” is the product of the interaction between different sensory modalities: when visual information (view of touch in rubber arm) is coherent with tactile information (feeling of tapping), vision dominates and the proprioception is displaced towards the position of the rubber arm.

In previous preliminary studies we have demonstrated that the “rubber hand illusion” can be also induced with a virtual, 3D projected, arm [5,6]. In the current study, we expand on previous work including new tactile, auditory and dynamical-visual stimuli. We examine to what extent participants can feel tactile sensations in the virtual hand and provide subjective and physiological evidence. Although audiotactile interactions may occur, they are beyond of the scope of the presented work and, thus, not included in this study.

2. MATERIALS AND METHODS

Ten healthy male subjects (26.30±8.98 years old; right-handed) participated in this study. Each subject sat on a chair over a platform and beside a mounted shoulder high wooden box (adjustable in height) and rested his right arm (hand flat with palm down) inside the box, so that the arm was hidden from his view. Participants wore stereo glasses and a head tracker and saw a virtual representation of a right arm on the display. Unlike previous studies [1,2], here we used tactile stimuli delivered by two air puffs (air pressure: 0.5 bar; stimulus duration: 0.2-0.5 s; inter-stimulus interval: 0.3-0.8 s). The visual input observed by the participant was a virtual spray can that provided air puffs at two different locations of the virtual hand. Synchronously with the virtual spray, two alternating air puffs stimulated randomly (random location, duration and inter-stimulus interval) on two positions of the hidden real hand of the subject. The sound of the air puff was heard by participants and came from the same spatial point where the virtual spray can was displayed. In the final ~6s of the experiment the virtual arm slowly rotated about its length. The movement consisted in a slow supination of the arm (up to 20°) and the subsequent pronation, returning to the initial position, the whole sequence lasting 6s approx. An EMG channel placed over the supinator muscle in forearm was recorded.

3. RESULTS

Participants filled out a 14-item questionnaire (7-point Likert scale) after the experiment (see Appendix 1). The first 9 questions corresponded to a modified version of the questionnaire used in the “rubber hand illusion” [1]. Questions 1, 2 and 9 indicated the presence of the illusion and the remaining questions were considered as control. The null hypothesis that the medians are all equal was rejected (Kruskal-Wallis nonparametric one-way ANOVA, $p < 2 \times 10^{-5}$). The medians of questions 1, 2, 7, and 9 were higher at the 5% significance level (Fig. 1). Further, we calculated for each question the number of subjects having scores ≥ 6 . Assuming that the number of high scores has a binomial distribution and the probability of a high score is $2/7$, we obtained that the number of questions 1, 2, 7 and 9 had frequencies that were very much higher than would be expected by chance (Fig. 2).

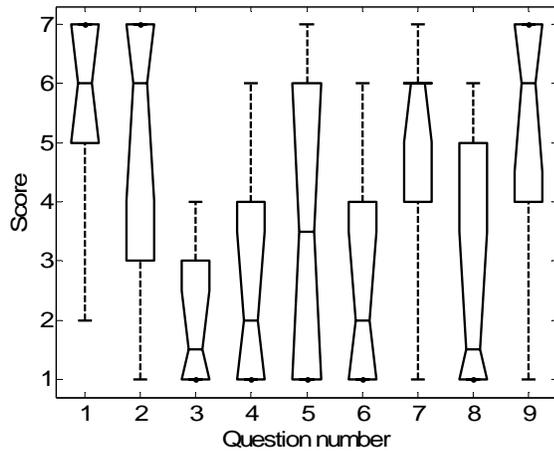


Figure 1. Box plot for scores of questions 1-9. The medians are represented by a horizontal line inside each box. The boxes are the interquartile ranges.

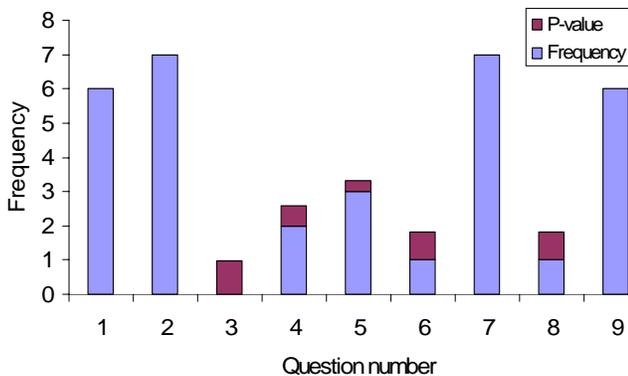


Figure 2. Frequency and significance values for high scores (≥ 6) for questions 1-9. The significance values to reject the hypothesis that the participants responses were due to chance, shown as P-values in the figure, are (1) 0.0079, (2) 0.0011, (3) 0.9654, (4) 0.5782, (5) 0.3127, (6) 0.8271, (7) 0.0011, (8) 0.8271, (9) 0.0079.

Five additional questions (10-14) were included in the questionnaire after many pilot experiments (see Appendix 1). The

median score of question 10 was significantly higher than the score of questions 11, 13 and 14 ($p < 0.05$; Fig. 3). Moreover, the frequency of high scores was very much higher than would be expected by chance as well (Fig. 4).

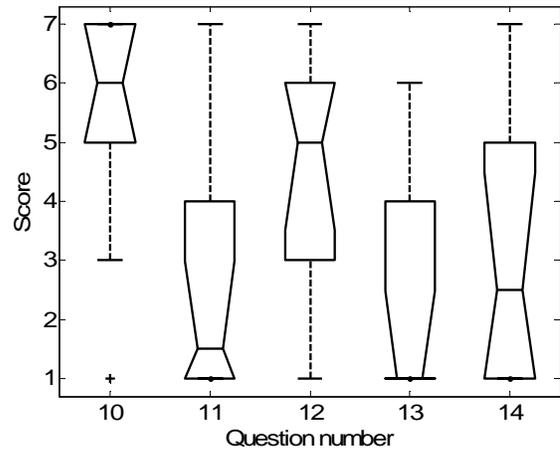


Figure 3. Box plot for scores of questions 10-14. The medians are represented by a horizontal line inside each box. The boxes are the interquartile ranges. Note that the question 10 shows an outlier (+).

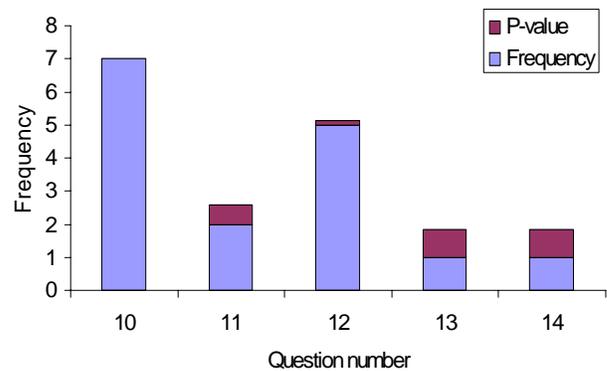


Figure 4. Frequency and significance values for high scores (≥ 6) for questions 10-14. The significance values to reject the hypothesis that the participants responses were due to chance, shown as P-values in the figure, are (10) 0.0079, (11) 0.5782, (12) 0.1269, (13) 0.8271, (14) 0.8271.

Regarding the recorded EMG activity, we examined the EMG root-mean-square (RMS) value of the first 4s of the virtual arm movement divided by the RMS value during the first 5 min. (RMS ratio), and compared it with the mean score of the illusion-related questions (1, 2 and 9). Although a positive correlation was observed (Fig. 5), the slope of the regression line was statistically non-significant ($p < 0.05$). Similar results were obtained for the first s seconds during the arm rotation for any $s \geq 1$.

Further, a semi-debriefing interview was completed. The most remarkable and repeated comments (positive as well as negative) were:

- Positive (all from different subjects):

“Sometimes I felt the virtual arm as mine”.

“The virtual arm looked quite similar to mine”.

“When the stimulation started, the sensation of ownership increased”.

“I liked when the arm rotated and wanted to move it to experience more things”.

“The movement of the virtual arm at the end seemed very real”.

- Negative (all from different subjects):

“I felt always my real hand”.

“When the virtual arm rotated, I have not thought it could be mine. This movement has broken the illusion”.

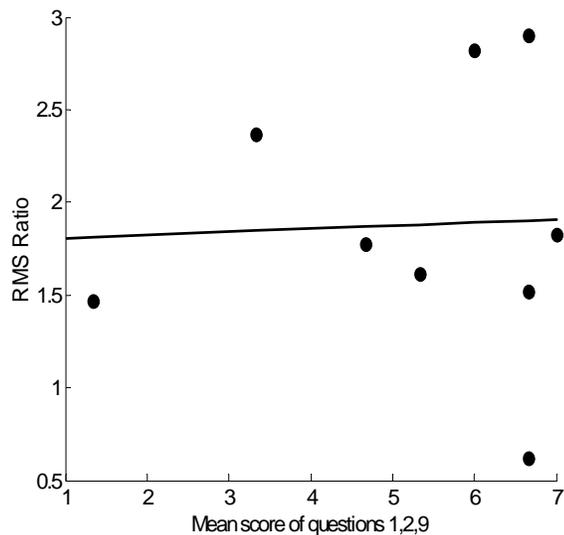


Figure 5. Scatter diagram of EMG RMS ratio by the mean score of questions 1, 2 and 9.

4. DISCUSSION AND CONCLUSIONS

The questionnaire results are conclusive and show that the illusion works. The score of the illusion-related questions was significantly higher compared with the control questions. These results confirm those from our previous work [5,6].

A correlation between EMG activity (when the virtual arm started moving compared to before it started moving) and the reported subjective strength of the illusion was observed. Further, the subjective data seem to support this finding, since the score of

question 10, related to the sensation of movement, was significantly higher and several subjects reported the wish to move their arm when the virtual arm did. However, the sensation of coldness reported by several subjects during the air-puffs experiment seemed to intensify the perception of their own real hand. These findings suggest that the “virtual hand illusion” also engages and deceives the motor system. Although the results of EMG data are encouraging and seem to corroborate the results obtained in previous studies, further investigation in this direction is needed.

Summarizing, there was a degree of feeling of ownership over the virtual arm as revealed by questionnaire results and EMG data. The illusion of ownership of virtual limbs provides a flexible tool for the study of body perception. Future studies will include additional physiological measures in order to extend the scope of the examinations that evaluate the degree of the experienced illusion and the displacement of ownership of the real arm towards the virtual arm.

5. ACKNOWLEDGMENTS

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APPENDIX 1 – QUESTIONNAIRE

Lee detenidamente cada una de las siguientes afirmaciones y pon una cruz en el lugar que corresponda, según tu grado de conformidad:

Read carefully each one of the following statements and place a cross in the place that corresponds to your degree of agreement.

- 1. Sometimes I had the feeling that I was receiving the air in the location of the virtual arm.**

En algún momento tuve la sensación de que estaba recibiendo el aire en el lugar en el que se encontraba el brazo virtual.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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- 2. During the experiment there were moments in which it seemed as if what I was feeling was caused by the spray that I was seeing on the screen.**

Durante el experimento hubo momentos en los que parecía como si lo que yo sentía fuera causado por el spray que veía en la pantalla.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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- 3. During the experiment there were moments in which it seemed that my real arm was being displaced towards the left (towards the virtual arm).**

Durante el experimento hubo momentos en los que parecía que mi brazo real estuviera desplazándose hacia la izquierda (hacia el brazo virtual).

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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- 4. During the experiment there were moments in which it seemed that the air that I was feeling originated in some place in between my own arm and the virtual arm.**

Durante el experimento hubo momentos en los que parecía como si el aire que estaba sintiendo viniera de algún lugar entre mi propio brazo y el brazo virtual.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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- 5. During the experiment there were moments in which I felt as if my real arm was becoming virtual.**

Durante el experimento hubo momentos en los que sentía como si mi brazo real se estuviera convirtiendo en virtual.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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6. **During the experiment there were moments in which it seemed (visually) that the virtual arm was being displaced towards the right (towards my real arm).**

Durante el experimento hubo momentos en los que parecía (visualmente) como si el brazo virtual se fuera desplazando hacia la derecha (hacia mi brazo real).

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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7. **During the experiment there were moments in which the virtual arm started to look like my own arm in some aspects.**

Durante el experimento hubo momentos en los que el brazo virtual comenzaba a parecerse a mi propio brazo en algunos aspectos.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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8. **During the experiment there were moments in which I had the sensation of having more than one right arm.**

Durante el experimento hubo momentos en los que tenía la sensación de tener más de un brazo derecho.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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9. **During the experiment there were moments in which I felt as if the virtual arm was my own arm.**

Durante el experimento hubo momentos en los que sentía como si el brazo virtual fuera mi propio brazo.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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10. **During the experiment there were moments in which I felt that if I moved my arm (real) the virtual arm would move.**

Durante el experimento hubo momentos en los que sentía que si movía mi brazo (real) se iba a mover el brazo virtual.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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11. **After doing the experiment I feel as if my right arm might be longer than normal.**

Después de haber realizado el experimento parece como si mi brazo derecho fuera más largo de lo normal.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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12. **After doing the experiment I feel my right arm tired, as if I had been doing some exercise.**

Después de haber realizado el experimento siento mi brazo derecho cansado, como si hubiese realizado algún tipo de ejercicio.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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13. At the end of the experiment I continued having the feeling of having a third arm.

Al terminar el experimento seguía teniendo la sensación de tener un tercer brazo.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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14. After doing the experiment I feel the right arm “dead” and the tips of the fingers cold.

Después de haber realizado el experimento siento el brazo derecho “muerto” y las puntas de los dedos frías.

TOTALMENTE EN DESACUERDO	1	2	3	4	5	6	7	TOTALMENTE DE ACUERDO
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