Virtual Hand Illusion: the Alien Finger Motion Experiment

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Abstract

In Virtual Reality, the need to understand how subjects perceive their representation is gaining attention and importance. We present a contribution to a better understanding of the sense of embodiment by assessing two of its main components, body ownership and agency, through an experiment involving alien motion. The key aspect of the experimental protocol is to integrate a condition with some personalized alien finger movement while the subject is asked to remain still. Body ownership appears to be significantly reduced, but not agency. We also propose a metric to assess quantitatively that the view of the alien movement induces more finger posture variation compared to the reference context in the still condition.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; I.2.0 [Artificial Intelligence]: General—Cognitive simulation;

1 Introduction

The sense of embodiment (SoE) consists in the belief of a person that an external body is their physical one. Two of the main components of the phenomenon are the sense of ownership (SoO) and the sense of agency (SoA) [5]. Alien motion is defined as the feeling that an external entity is causing the movements of our own body, and Virtual Reality (VR) can be an ideal environment to investigate these concepts [7]. Numerous studies on embodiment have been carried on, underlying that several factors have an impact on the SoE, including the graphic representation of the avatar [6], the interaction with the environment [1], the bodily structural changes [3]. In particular, the probability of SoO over the avatar body, grows in case of visuomotor synchrony (i.e. a real-time representation of the movements with no alien motion) despite of its form [8]; the SoA allows (robotic) intermediaries without necessarily being affected [2], while SoO decreases.

The aim of our work is to investigate, in VR, the behavior of SoO and SoA in an experimental design that includes alien finger motion. Compared to a realtime representation, in case of alien motion we expect SoO, and not necessarily SoA, to decrease (**H1a**); and SoO and SoA to lose their correlation (**H1b**). Moreover, the induced movements can be quantified by some metrics to measure the ad-personam impact of the alien motion in a given setup (**H2**).

2 The Alien Hand Motion Experiment

We aim at making users reach a sense of ownership and agency, then perform some alien motion (without them being aware) and sense their reactions to the experience, the visualized movements being user's own movements, not a pre-recorded general movement or a computer animation. The first important notion is the basic hand pose used during the experiment: without forcing any movements, while people look at their palm, the hand stays *still*. We also define

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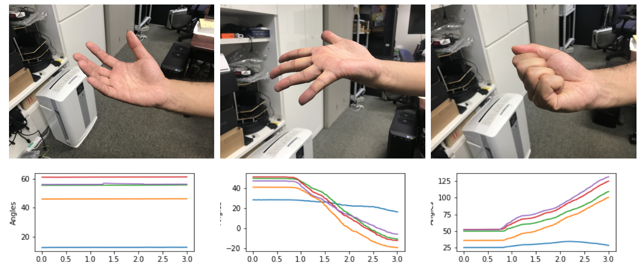

Figure 1: In the upper row, the hand of a subject in the *still* position, and at the end of the *open* and *close* movements. Under each, a visualization of the timeseries of the movements of the fingers in the three different cases.

two movements: the transition between *still* and the fist is called *close*, while the transition between *still* and the forced wide open hand is called *open*. Sixteen volunteers were invited to take part to the experiment: 14 males and 2 females, 6 never tried VR before, with an average age of 28.8 and a standard deviation of 7.0. They experienced two different conditions, C1 visualizing the realtime representation of their movements, and C2 visualizing the experimental pattern described below. **Phase 0: recording the baseline and the motions.** Users wear a sensing glove (Senso Glove) and look at their palm, while the operator records 3s of *still*, that will be used as a baseline, and 3s of *open* and 3s of *close* for playback purposes. In Figure 1, we can see how the three basic movements look in a graph where the x axis represents time, and the y axis represents the amplitude of the angles of the 5 fingers with respect to the hand. **Phase 1: experiencing condition C1.** Users wear the HMD (HTC Vive) and get familiar with the system; then fill the first questionnaire, related to C1. **Phase 2: experiencing condition C2.** Users go through 18 series, every of which is structured as follows. They hear the first audio stimulus, they look at their palm and start opening and closing their hand, in particular performing continuously, as asked, *still* $\rightarrow$ *open* $\rightarrow$ *still* $\rightarrow$ *close* $\rightarrow$ *still* and so on, according to their favorite pace. When the second audio stimulus occurs, they stop the movements and stay in *still* position, always looking at their palm. For 3s they visualize the real position of their hand, and for the following 3s they visualize an alien motion (recorded in Phase 0), without having been previously informed. The third audio stimulus finally happens, the series is over and the environment turns to black. The next series starts when the scene reappears and a new audio stimulus defines the beginning of the next series. At the end of the 18 series, subjects answer questionnaire related to C2.

3 Measures of the Illusion

The questionnaire we used to quantify the SoO and the SoA as O and A, as well as their control statements as OC and AC, is a readjustment of the one proposed by Kalckert and Ehrsson [4] for their studies on the dissociation of ownership and agency. Since we work in VR, our questionnaire refers to the Virtual Hand instead of the Rubber one. Answers were given on a 7 point Lickert scale, where -3 represents a total disagreement and +3 a total agreement with the 16 sentences, where 1 to 4 are related to SoO, 5 to 8 to the SoO control statements,

C1			
Ownership	**O Control**	**Agency**	**A Control**
$\mu(O) = 1.42$	μ(OC)=-1.25	$\mu(A) = 1.97$	μ(AC)=-1.81
$\sigma(O) = 0.07$	$\sigma(OC) = 0.88$	$\sigma(A) = 0.28$	$\sigma(AC) = 0.51$
O vs 0	**O vs OC**	**A vs 0**	**A vs AC**
$p < 0.05$	$p < 0.05$	$p < 0.01$	$p < 0.001$
C2			
Ownership	**O Control**	**Agency**	**A Control**
$\mu(Oa) = 1.02$	μ(OCa)=-1.29	$\mu(Aa) = 1.5$	μ(ACa)=-1.59
$\sigma(Oa) = 0.15$	σ(OCa) = 0.90	$\sigma(Aa) = 0.19$	σ(ACa) = 0.27
Oa vs 0	**Oa vs OCa**	**Aa vs 0**	**Aa vs ACa**
$p < 0.01$	$p < 0.05$	$p < 0.001$	$p < 0.05$
O vs Oa		**A vs Aa**	
p < 0.05		p = 0.06	

Table 1: Overview of the values and significance tests of SoO and SoA in C1 and C2.

9 to 12 to SoA, 13 to 16 to SoA control. We first considered the mean value of the answers of all the 16 users to each question (1 to 16) $\mu_1, ..., \mu_{16}$, and their standard deviation $\sigma_1, ..., \sigma_{16}$. We then quantified the SoO as $O = [\mu_1, ..., \mu_4]$, its mean value $\mu(O) = \mu(\mu_1, ..., \mu_4)$, and its standard variation $\sigma(O) = \sigma(\mu_1, ..., \mu_4)$. The same method we used to quantify all the variables in C1 (O, OC, A, AC) and in C2 (Oa, OCa, Aa, ACa, where a denotes the presence of alien motion). We run an unpaired two-sided t-test to investigate SoO and SoA: in both conditions, C1 and C2, O and A are significantly above 0 and above the value of their control statements. We then explored the impact of the alien motion on SoO and SoA through an analysis of the variance (ANOVA) in the two conditions, and spotted a significant difference in the SoO, but not in the SoA. The values are reported in Table 1.

We finally spotted some per person correlations (Pearson $\rho > 0.5$, $p < 0.05$) between O and A in C1, and that did not happen in C2.

4 Measures of the Induced Movement

To measure the movements of the fingers of the users, we introduce the quantifier D. Given the angle θ_t, the angle of one finger in a given time instant t, we define D, the quantifier of the movement of the finger in the time interval $(0, T)$, as the sum of the samples of θ_t.

$$D = \sum_{t=0}^{T} \theta_t \tag{1}$$

We define

- Ds_{if} as the amount of movement D of the finger f during the *still* baseline of one participant i; to every participant i we therefore associate 5 Ds values (1 per finger).

- Da_{ifj} as the amount of movement of one person i during one single Alien Motion Session j, calculated per finger f. We are associating per person 18x5=90 Da values (18 per finger).

We proceed calculating Da_{if} as the mean value of the movements of each finger f in all the N=18 sessions j.

$$Da_{if} = \left| \frac{1}{N} \sum_{j=1}^{N} Da_{ifj} \right| \tag{2}$$

We set the zero angle to the lower value of the distributions Da_{if} and Ds_{if}, then considered all of the Ds_{if} samples as members of one whole population, called Ks according to the previous nomenclature, composed of 16 participants x 5 fingers = 80 values. In the same way, we refer to Ka as the population of the values of Da_{if}. We therefore proceed calculating the mean and standard deviation of Ka and Ks,

Ka	**Ks**	**Ka vs Ks**
μ = 15.98	μ = 13.11	t = 3.29
σ = 6.50	σ = 4.23	p < 0.01

Table 2: Values and significance tests of the amount of movement.

as well as performing a t-test between Ka and Ks, attempting to establish that $Ka > Ks$. Ka appears to be significantly different from Ks with a desirable probability value, as shown by the results in Table 2.

5 Discussion

Our experimental design preserved SoO and SoA (**H1a**), yet some alien motion was included in the pattern, but several aspects of the experimental design can be discussed. The results of the significance test we provided state that SoO significantly decreased, while SoA did not, even if the value of p=0.06 suggests a trend. While the decrement might be provided by the presence of alien motion, further combinations of experimental design and crossed data analysis will underline how much the result is due to the whole experimental pattern, the presence of alien motion, the personalized motion, or other factors.

The SoO and the SoA presented some correlations in C1, but not in C2, that supports (**H1b**). In ideal conditions (C1) subjects who had a higher SoA, also had a higher SoO, and vice versa. We could not spot the same correlation in C2, that suggests that the experimental process, including the presence of the alien motion, broke the spotted correlation, probably causing some confusion in the users that reacted in different ways.

We defined a metric and proposed a method for the measurement of the induced movements, based on the net amount of movement of a subject compared to their personal usual motorial behavior (**H2**). Since Ks is defined as the amount of movement performed by a person asked to stay *still* and look at their hand, results suggest that the amount of movement during alien motion (Ka) significantly differs from it. While we found the quantifier to be appropriate for the described experiment, we might need a more generalized approach to quantify the induced movements in future cases in which the expected motion will not be monotone.

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