

# Phantom Sensation: When the sensation escapes the bounds of the actuators and the end-point is sensed in the air

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**Abstract**—The use of tactile illusions allows users to interact easily with virtual environments or to guide disables people.

In this paper we address the problem of localization, or distance estimation when using a Phantom Sensation. More specifically, the perception of the end-point of a Phantom sensation has been investigated.

In our investigation, we used two handles with different lengths. Each of them equipped with two vibro-tactile actuators. While the actuators spacing has been kept constant (70 mm), the duration of the Phantom Sensation have been varied. It ranges from 0.25 s to 2.5 s.

Our conclusion is that the perception of the end-point depends on the duration: the end-point of the Phantom Sensation can be perceived out of the grasp or even out the handle.

## I. INTRODUCTION

The tactile sensory channel is widely used in human machine interfaces as it is an easy and safe way to convey information without hindering the other senses. For instance, it has been used to extend the capabilities of current mice [1], to guide the motion of people upper limb in a two dimensional space [2] or to convey tactile information in case of amputation [3].

Conveying tactile information can be based on tactile motion illusions, which have been studied since the beginning of the last century [4]. A tactile illusion is usually described as a discrepancy between an expected perception of a physical stimulus and the actual perception that is usually surprising and perplexing [5].

In his paper [4], Burt found that under some conditions of intensity, spacing and time, participants could perceive a motion between two tactile stimuli. Whether the perceived motion is discrete (the rabbit illusion [6], [7]) or continuous (the phantom sensation [8]), they can convey an information of direction [9], [2].

During Phantom Sensations, spatiotemporal interactions are at play. Alles explains in [8] that the phantom sensation may arise from a combination of temporal and amplitude inhibitions. First, he explains that 2 stimuli of equal amplitude, actuated subsequently with a short time delay will be perceived as one stimulus whose position is defined by the time delay, often called Inter-Stimulus-Onset-Interval (ISOI) [10]. Then, he explained that 2 stimuli of varying amplitude will be perceived as a motion between these 2 stimuli. The perceived position is hence modified by a change of

amplitude through time. This all adds up to the fact that there is a close relationship between the perception of distance and time [11].

Berger *et al.* [12] explained that the perceived area of stimulation is not always at the location of the physical contact with the skin. In the described experiment, participants were holding different objects in their hands, while seeing only one object between their hands in a Virtual Reality Display. Participants felt the motion going from one hand to another. More generally, it has been observed that a tactile stimulation can even be perceived out of the body, on an object held on both sides by participants' hands ([13],[12],[14],[15]). Miyazaki *et al.* explain in [13] this mis-localisation outside of the body by saying that the object is added to the mental scheme of the body. In all these studies, the mis-localisation studies, the end point of the illusion never went beyond the area defined by the actuators.

The Phantom Sensation described in [8], seems appealing and reported to have great direction detection success rate. However, Alles in [8] found that depending on the displayed Phantom Sensation, the end point of the phantom sensation could not be perceived easily, if not at all, by participants.

However, this motion illusion could be more efficient in applications such as assistance, rehabilitation or virtual reality systems, if the end-point is made clearer.

The comment of Alles in [8] interrogated us and we wanted to carry out a study on the Phantom Sensation end point perception.

A preliminary investigation of the perception of the distance travelled by a Phantom Sensation, i.e. its end-point, was conducted. This investigation aim to study whether the end-point of a phantom sensation could be perceived in area outside the actuators location, outside the body or even in the air.

In this paper, three experiments have been conducted. the first one allowed us to show that the direction detection is independent of the stimulation duration. The second experiment shows that the end of the phantom sensation can be perceived out of the hand palm. The third one shows that the end could even be perceived out of the grasped handle, in the air. To this end, we used two custom handles with different lengths. In both of

The duration of the phantom sensation were varied but the maximal amplitude of stimulation was the same across durations.

Here we show that a tactile stimulation can be perceived beyond the stimulators positions, out of the body, whether it is on an object or in the air beyond. These mislocalisations

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seem related to the duration of the tactile illusions.

## II. MATERIAL AND METHODS

### A. Experimental setup

The experimental setup is schematized in Fig. 1. It comprises a generic laptop computer, a multifunction card NI USB6001 by National Instruments, two audio amplifiers CS-PA1MK from Dynavox, and two handles equipped each with two recoil type custom-made actuators. The actuators have been built based on the recommendation of [16].

Two handles of different length have been used during the experiments. Both handles consist in a T-shape support composed of two equal halves. Two actuators vibrating tangentially are embedded into each handle and placed 7 cm apart. This spacing was determined experimentally as the approximate length of a hand palm.

A 1 mm gap between the two halves is meant to reduce the interference between the two actuators. Moreover, the two actuators are enclosed into a silicon material to further enhance their isolation.

The long handle is depicted in Fig 2. Its length is equal to 345 mm. The short handle is depicted in Fig 3, with a total length of 143 mm.

The short handle was design to test whether a out of handle motion could be elicited. Hence the length of the short handle was chosen to answer the following requirements:

- the length of the handle must correspond to a distance perceptually travelled by the phantom sensation so out of handle motion can be perceived.
- the length must be slightly bigger than the size of the hand,
- the handle must be comfortable to grasp,
- the participant should not be in contact with the edges hence giving him information about the dimensions of the handle that is hidden in experiment 3.

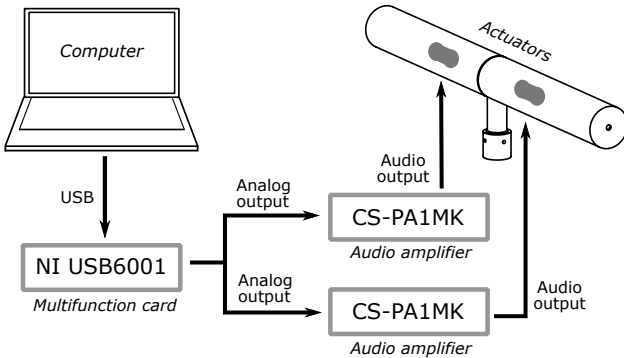


Fig. 1. Experimental setup scheme.

The setup works as follows: MATLAB is used to generate the two signals aimed to activate the vibrotactile actuators that yield the tactile illusion. The outputs of the NI USB6001 card, running at 2 kHz rate and connected via USB to the computer, are used for the digital-to-analog conversion. The

outputs are finally amplified using the two audio-amplifiers before sending them to the actuators.

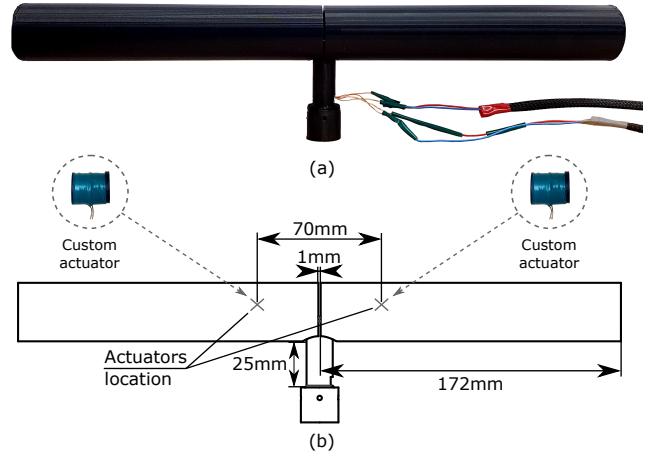


Fig. 2. (a) A picture of the long handle. (b) The long handle sagittal section.

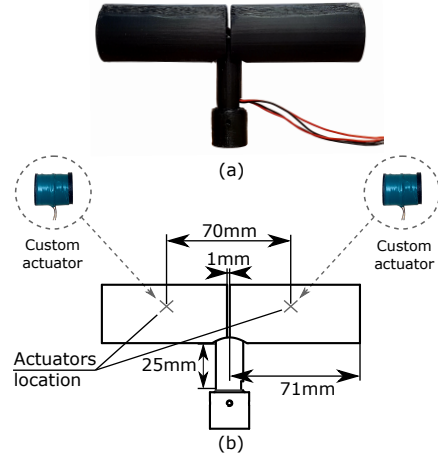


Fig. 3. (a) A picture of the short handle. (b) The short handle sagittal section.

For the experiment 2 and 3, 2 sheets of paper were used. The drawing in Fig. 4(a) is the participant's sheet. It represents the long handle. The grayed area represents their grasp on the handle. The drawing shown in Fig. 4(b) is the experimenter's sheet. The drawing is divided into 9 areas. The area 0 is the central area corresponding to the grasp and the position of the actuators. The rest of the drawing is divided equally into 3 areas on each side of the 0 area. Areas in the backward direction were noted with a minus sign and transition lines were also drawn. Areas 4 and -4 correspond to the outside of the handle. The short handle corresponds to the areas -1, 0 and 1.

### B. Stimuli

First, The actuators of both handles were tuned to provide equal intensity.

The tactile stimuli corresponding to the phantom sensation as described in [8] were synthesized. The duration

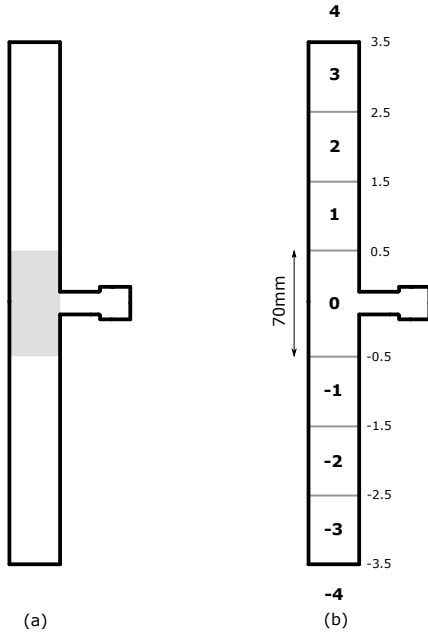


Fig. 4. (a) Drawing showed to the participants. The grayed area represents the hand palm contact. (b) Drawing used by the experimenter.

of the phantom sensations were varied to last between 0.25 and 2.5s. Fourteen phantom sensations in total were synthesized, 7 different durations for each direction (forward or backward). The 7 durations are the following: 0.25, 0.5, 0.75, 1, 1.5, 2 and 2.5s.

As explained in [8], the envelope of the 2 signals of a phantom sensation must not be linear as it would be detrimental to the illusion as the total perceived amplitude of the two signals would not be constant. Here, the chosen envelope, for all the signals, is an arc-tangent function. It was the envelope that elicited the least perceived change in amplitude during the vibration point motion. This envelope is similar to a logarithmic function. All envelopes were normalized in order to have the same maximal amplitude across all durations. The carrier signal is a sawtooth signal of 80Hz filtered using a 1st order Butterworth with a cutting frequency of 40Hz.

An example of a stimuli showing the two signals used to drive the two actuators for the 0.25 s duration is shown in Figure 5. One should notice that the envelope of the signal shown, chosen to clearly expose the carrier signal, is quite linear for this length as the duration is very short and that it is hence not representative of the envelope of all signals.

### C. participants

None of the participants who took part in the experiment reported any motor, sensory or neural disorders. They were unaware of the aim of the study, and have given their informed written consent.

a) *Experiments 1 and 2:* 12 subjects (10 male, 2 female, with ages ranging from 23 to 28 years old) volunteered to participate in the experiment 1 and experiment 2.

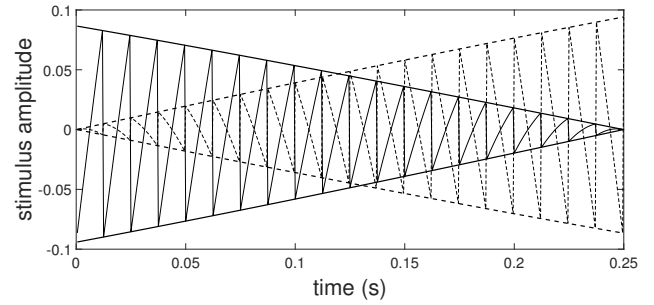


Fig. 5. Example of a signal generated. This signal was used for the phantom sensation of a duration of 0.25s. The full lines represent the signal generated and sent to the actuator 1 (envelope and carrier signal) and the dashed lines represent the signal generated and sent to the actuator 2 (envelope and carrier signal)

b) *Experiment 3:* 5 subjects (3 male, 2 female, with ages ranging from 24 to 29 years old) volunteered to participate in experiment 3.

### D. Experiments and testing conditions

Subjects sat comfortably and held the handle horizontally by the middle with their right hand. The handle was maintained along their sagittal plane.

Subjects wore headphones with pink noise and closed their eyes during the experiment to avoid any inter-modality bias. The lights in the experimental room were dimmed. They received no feedback during the experiments. At the end of the experiments, an informal discussion took place with each participant to record their general impressions. These impressions concerned the clarity of the information, the perceived speed of the motion and whether they felt a relationship between the duration of the duration and the distance travelled or any comment they thought relevant.

1) *Experiment 1 - Discrimination of the direction:* In this experiment, the long handle has been used. It was conducted in order to check if the duration influences the direction detection.

In order to avoid fatigue, only three durations have been tested: the shortest (0.25 s), the longest(2.5 s) and one in-between (1 s).

A two-alternative forced choice protocol was used to validate the discrimination of the direction of the phantom sensation. For each duration, pairs of forward/backward, backward/forward, forward/forward, and backward/backward have been prepared. This makes a total of 4 pairs for each duration, hence 12 pairs for all the tested durations. Each pair was repeated 5 times in a randomized order leading to a total of 60 pairs of signals per participant. Pair by pair, the subject was presented a pair of signals and then asked to report which signal of the two presented was going forward. The experimenter recorded the answer for each pair.

The experiment 1 lasted approximately 20 minutes.

2) *Experiment 2 - Out of hand detection:* In this experiment, the long handle was used. Participants saw the handle and knew that it was approximately equal in dimension to

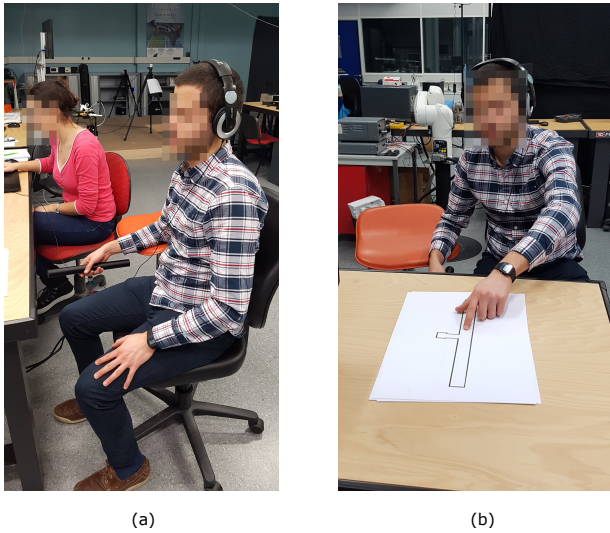


Fig. 6. Participant performing the (a) Experiment 1 (b) Experiment 2 or 3.

the drawing placed in front of them. The drawing is shown in Fig. 4(a). The participants were explained that the grayed area represented their grasp on the handle.

Participants were presented stimuli and informed of their direction and were asked for each to locate the end of the movement on the sheet of paper in front of them. After each stimulus, the participant's answer was recorded by the experimenter using the areas presented in II-A and shown in Fig. 4(b).

Each of the 14 stimuli described in II-B was presented 5 times in a random order leading to 70 randomized trials separated by rest periods.

The experiment 2 lasted approximately 20 minutes.

3) *Experiment 3 - Out of handle detection*: In this experiment, the short handle was used. Participants did not see the handle.

Participants were presented stimuli and informed of their direction and were asked for each to locate the end of the movement on a sheet of paper with a drawing of a handle in front of them. The drawing presented to the subject is shown in figure 4(a). The drawing presented for this experiment was the same as the one used for the experiment 2. After each stimulus, the participant's answer was recorded by the experimenter.

Each of the 14 stimuli described in II-B was presented 5 times in a random order leading to 70 randomized trials separated by rest periods.

The experiment 3 lasted approximately 20 minutes.

### III. DATA RECORDING, ANALYSIS AND RESULTS

The data collected during our experiments did not have a normal distribution. For this reason, medians and interquartiles ranges were used to represent them. Non-parametric tests were also used for the statistical analyses.

1) *Experiment 1 - Discrimination of the direction*: Fig. 7 shows a boxplot of the direction detection probability. 1 and 0 represent, respectively, the probability of detection of the

direction 100% and 0% of the time. In this plot, all the data from all the participants are pooled together.

Even if the best estimation seems to occur for a 1 s duration, a Friedman test showed that there is no significant difference between the three durations ( $p > 0.05$ ).

One can conclude that the duration may not affect the probability of detecting the direction of a phantom sensation.

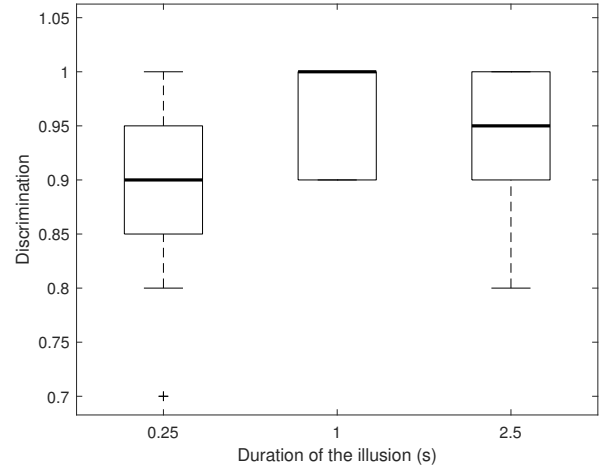


Fig. 7. Experiment 1 - Boxplot of the probability of discrimination of the direction depending on the duration of the illusion. The diagram shows the median observation. The lower and upper quartiles are also represented. Data falling outside the interquartile range are plotted as outliers of the data.

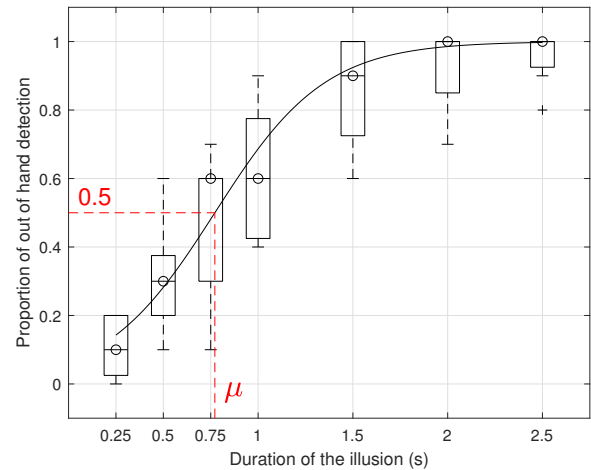


Fig. 8. Experiment 2 - Psychometric curve of the detection of the ending of the movement out of the hand as a function of the duration of the illusion. The median data for all participants who perceived in and out of hand movement, represented with boxplots, were used to compute this psychometric curve. The point of out of hand of hand perception  $\mu = 0.77s$  is plotted.

2) *Experiment 2 - Out of hand detection*: As explained in II-D, after the pointing of the participant on the sheet depicted in Fig. 4(a), the experimenter records the given answer based on the drawing presented in Fig. 4(b).

The areas 0.5, 1.5, 2.5 and 3.5 were grouped with the areas 0, 1, 2 and 3 respectively and the areas  $-0.5, -1.5, -2.5$

and  $-3.5$  were grouped with the areas  $0, -1, -2$  and  $-3$  respectively. Furthermore, the two directions were treated together *i.e.*  $-1$  and  $1, -2$  and  $2, -3$  and  $3, -4$  and  $4$  were grouped together in the following groups: 1, 2, 3 and 4.

The data has been separated into 3 groups:

- the participants who perceived the end of the stimulation both in and out of their hand. This group comprises 7 out of 12 participants.
- the participants who perceived the end of the stimulation mostly or only in their hand (only the areas' numbers  $0, 0.5$  and  $-0.5$  are reported). This group comprises 3 out of 12 participants.
- the participants who perceived the end of the stimulation mostly or only out of their hand (only areas 1 or bigger or  $-1$  or lesser are reported). This group comprises 2 out of 12 participants.

For each group a psychometric curve is drawn. For the first group, the psychometric curve is drawn in Fig. 8. For the two other groups the curves are drawn in Fig. 9. The point of out of hand perception,  $\mu$ , is the duration at which the psychometric curve crosses a probability of 0.5. For the first group, reporting in and out of hand perception,  $\mu = 0.77s$ .

Fig. 10 represents a heatmap of the percentage of detection in an area depending on the duration. As explained, the hand corresponds to the area 0 of the drawing hence a detection in the area 1 or above or  $-1$  or less is not in the hand. It was computed for all participants of the 3 groups pooled together. The heatmap seems to suggest that there is a relationship between the duration and the perceived area containing the ending-point of the movement.

The end of the movement was perceived 67% of the time out of the hand. The end of the movement was perceived 48% of the time in the area 1 or  $-1$ . These areas are close to the hand but out of the grasp.

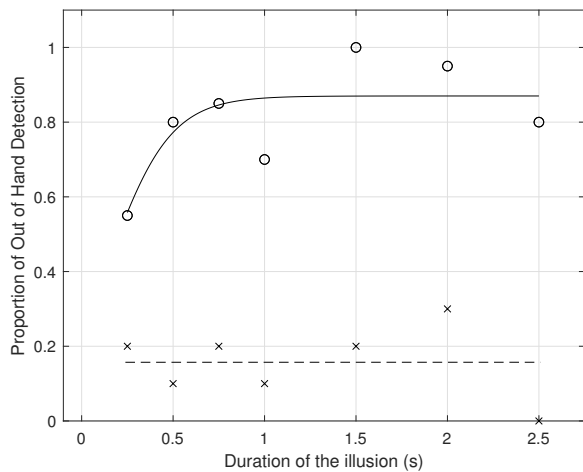


Fig. 9. Experiment 2 - Psychometric curve of the detection of the end-point of the movement out of the hand as a function of the duration of the illusion for all participants who perceived mostly in or mostly out of hand movement. The full line and 'o' correspond to the out of hand participants. The dashed line and 'x' correspond to the in hand participants.

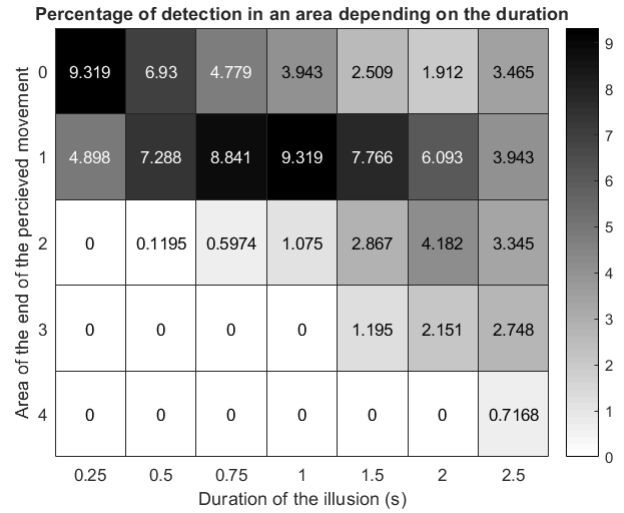


Fig. 10. Experiment 2 - Heatmap of the percentage of detection in an area depending on the duration for all participants. The areas  $0.5, 1.5, 2.5$  and  $3.5$  were grouped with the areas  $0, 1, 2$  and  $3$  respectively and the areas  $-0.5, -1.5, -2.5$  and  $-3.5$  were grouped with the areas  $0, -1, -2$  and  $-3$  respectively. The two directions were treated together *i.e.*  $-1$  and  $1, -2$  and  $2, -3$  and  $3, -4$  and  $4$  were grouped together.

3) *Experiment 3 - Out of handle detection:* 1 subject out of the 5 was discarded because the subject explained after the experiment that his/her answers were not based not on the perceived area.

Figure 11 shows the psychometric curve for the answers pooled across the 4 retained participants. The point of out of handle perception,  $\mu$ , is the duration at which the psychometric curve crosses a probability of 0.5.  $\mu = 1.5s$  for out of handle perception.

Fig. 12 represents the heatmap of the percentage of detection in an area depending on the duration. It was computed for the retained participants. As explained, the handle corresponds to the area  $0, -1$  and  $1$  of the drawing hence a detection in the area 2 or above or  $-2$  or less is not in the handle. As for experiment 2, the areas  $0.5, 1.5, 2.5$  and  $3.5$  were grouped with the areas  $0, 1, 2$  and  $3$  respectively and the areas  $-0.5, -1.5, -2.5$  and  $-3.5$  were grouped with the areas  $0, -1, -2$  and  $-3$  respectively. Furthermore, the two directions were treated together *i.e.*  $-1$  and  $1, -2$  and  $2, -3$  and  $3, -4$  and  $4$  were grouped together. The heatmap seems to suggest that there is a relationship between the duration and the perceived area containing the end-point of the movement.

The end of the movement was perceived almost 20% of the time out of the hand. The end of the movement was perceived 16% of the time in the area 2 or  $-2$ . These areas are close to the handle but out of the it.

#### IV. DISCUSSION

The experiment 1 showed that the duration had not effect on the discrimination of the direction for durations between  $0.25$  and  $2.5s$ .

The experiment 2 showed that, for more than half of the participants, if the duration of the phantom sensation

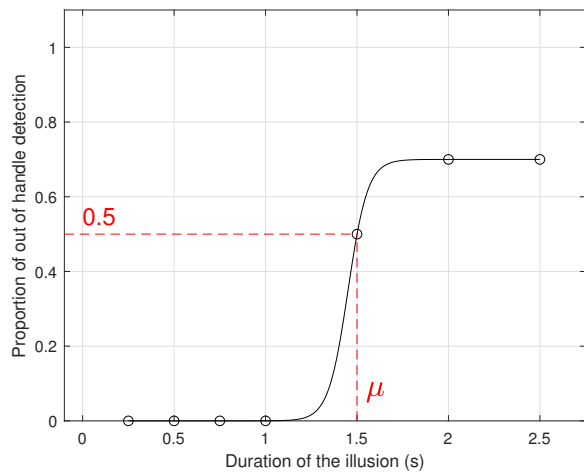


Fig. 11. Experiment 3 - Psychometric curve of the detection of the end-point of the movement out of the handle as a function of the duration of the illusion. The median of the data of the 4 retained participants were used to compute this curve. The two directions were treated together *i.e.* -1 and 1, -2 and 2, -3 and 3, -4 and 4 were grouped together. The 'o' correspond to the median values. The point of out hand of object perception  $\mu = 1.5s$  is plotted.

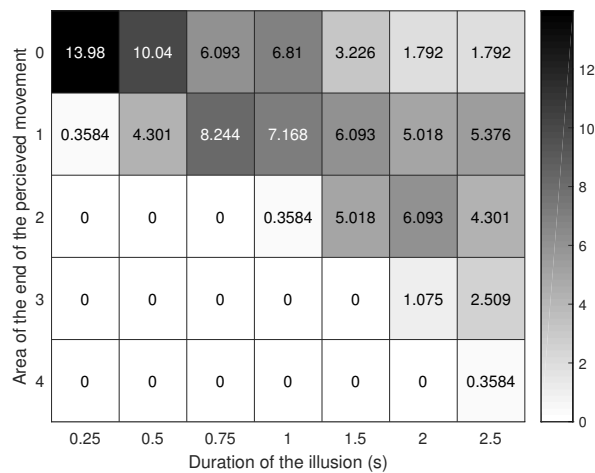


Fig. 12. Experiment 3 - Percentage of detection in an area depending on the duration for the 4 retained participants. The areas 0.5, 1.5, 2.5 and 3.5 were grouped with the areas 0, 1, 2 and 3 respectively and the areas -0.5, -1.5, -2.5 and -3.5 were grouped with the areas 0, -1, -2 and -3 respectively. The two directions were treated together *i.e.* -1 and 1, -2 and 2, -3 and 3, -4 and 4 were grouped together.

is greater than  $\mu = 0.77s$ , then the end of the motion is perceived out of the hand, in the handle.

The experiment 3 showed that if the duration of the phantom sensation is greater than  $\mu = 1.5s$ , then the end of the motion is perceived out of the handle, in the air.

The experiment 2 showed that for some participants, the end of the motion of either always in the end or always out of the end.

*A. Mechanisms likely responsible for the out of hand and out of object perception*

- INVARIANT SPATIOTEMPOREL

- RELATION ENTRE DUREE ET DISTANCE VISIBLE DANS LES HEATMAP
- MU OBJET EST SUPERIEUR A MU MAIN CE QUI VA DANS LE SENS DE DUREE ET DISTANCE
- IDEE QUE L'OBJECT EST AJOUTE AU SCHEMA CORPOREL
- QUAND ON NE VOIT PAS L'OBJET, ON NE CONNAIT PAS SA LONGUEUR ET DONC IL DEVIENT PLAUSIBLE QU'ON PERCOIVE QUELQUE CHOSE PLUS LONG QUE LUI

*B. Mechanisms likely responsible for the only in hand perception*

- PLUSIEURS SUJETS QUE DANS LA MAIN ONT EXPLIQUES APRES L'EXPERIENCE QU'ILS AVAIENT RESSENTIS DES VARIATIONS DE VITESSES ET DONC L'INVARIANT NE TIENT PLUS [17]
- IL SENTE TROP LA VIBRATION DANS LEUR MAIN POUR CONCLURE QUE CA A ETE PLUS LOIN

*C. Mechanisms likely responsible for the out of hand perception*

- SURESTIMATION DE LA DISTANCE PARCOURUE
- TROUVER AUTRE CHOSE

IDEES A UTILISER:

- comparer les  $\mu$  des experiences 2 et 3
- spatiotemporal invariant. For a movement, if speed is constant, an increased duration is perceived as an increase of distance.
- subjects who perceived only in hand movement felt different speeds hence the invariant does not hold and duration and distance are not linked anymore.
- subjects only out of hand: maybe a overestimation of the distance compared to the rest of the subjects.
- out of the object: other people do from an object to an other going into thin air, we do from an object to thin air without any stimulation after thin air.

ESSAYER D'UTILISER CA "a model in which spatial or temporal judgments in context are a weighted average of the given interval, temporal or spatial, and the expected time or distance that would be traversed at a given velocity. Consequently, it is argued that the functional relations between distance, duration, and velocity provide a natural context for distance and duration judgments." Jones, Bill, Huang, Yih Lehr dans "Space-time dependencies in psychophysical judgment of extent and duration: Algebraic models of the tau and kappa effects."

ESSAYER D'UTILISER CA AUSSI "Statistical regularities of physical motion are therefore a natural context not only for relational judgments but also for perception of the location of individual stimuli." "Temporal aspects of the stimulus may affect perception of its spatial properties, and vice versa." "Our results strongly support the hypothesis that perceived terminal position of a moving object is susceptible

to a constant-velocity bias.” ”velocity-dependent compressive mislocalization (position shift).” ”Our spatiotemporal account needs to explain the origin of the observed bias against sudden accelerations. Its possible origin is experience with moving objects accumulated through evolutionary and personal experience.” [17]

ESSAYER D’UTILISER CA AUSSI en tant en contact avec un signal, sa perception change. Peut peut-être expliquer l’évolution du comportement au cours du temps. c’est en vision mais on peut faire le parallèle ”Rapidly learned stimulus expectations alter perception of motion” de Matthew Chalk, Aaron R. Seitz Peggy Seris

”discrimination of the direction of motion on the human hand a psychophysical study of stimulation parameters” de

”Temporal delay did have, however, an effect on overall lateral shifts in localisation.” dans ”Spatiotemporal integration of tactile patterns along and across fingers” de Jrg Trojan a,b,n, MaruschkaHeil c, ChristianMaihfner d,e, RupertHlzl b,c, DieterKleinbhl c, HertaFlor b, JustusBenrath

#### D. The limits of the study

The use of a graphical interface to record the exact position of the end-point of the movement could have been used in order to obtain more precise data about the position of the end-point.

Only 12 participants were tested for the experiment 1 and 2 and only 5 for the experiment 3. The study could be improved by an increased number of participants. The distinction between the subjects who felt only in hand or only out of hand perception and the ones in and outside of the hand/handle could have been made clearer thanks to the increased number of participants.

During the experiment 1, the participants were asked to report a forward direction and never the backward direction. This study could be improved by repeating the experiment 1 but in this case, the backward direction would be asked to identify.

The results of the experiment 2 and 3 group areas by distance without consideration of the direction of the motion. [17] reports that there is a difference of distance perception depending on the direction. Indeed, there could be a difference due to a preferred direction or due to a different sensitivity depending on the area of the hand. The psychometric curve could be drawn for the two directions (forward and backward) separately. The heatmap of the area as a function could be computed depending on the direction. Moreover, the experiment 2 and 3 could be repeated by changing the way that the handle is grasped to study the second possibility.

Different velocity were reported in the discussion with the participants and velocity as an influence on the position perceived [17]. For these reasons, the experiments 2 and 3 could be repeated but this time the participants would be divided into 2 groups, one group would be informed that the velocity is constant and the other would be not be informed of this fact.

As explained before in REF DE LA SECTION, Chalk et al in [18] explain that, for vision, the expectation of a rapidly learned stimulus can alter the perception of a motion hence alter the perceived end-point of the position. To study the possible effect, an analysis of the evolution of the answers though time could be done.

## V. CONCLUSION

### FOR FUTURE WORK PART:

- study of the visual bias: use to two groups for the exp3, one who sees the handle and another who does not.
- see if there is a difference if the phantom sensations go to the left and right and not forward and backward since bias exist between vertical/horizontal (ref).

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