Speed Discrimination in the Apparent Haptic Motion Illusion

Inès Lacôte, David Gueorguiev, Claudio Pacchierotti, Marie Babel, Maud Marchal

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I. Lacôte[1], D. Gueorguiev[2], C. Pacchierotti[3], M. Babel[1], and M. Marchal[1,4]

[1] Univ Rennes, INSA Rennes, IRISA, Inria, CNRS – Rennes, France
[2] CNRS, Sorbonne Université, ISIR – Paris, France
[3] CNRS, Univ Rennes, Inria, IRISA – Rennes, France
[4] Institut Universitaire de France (IUF) – Paris, France

Abstract. When talking about the Apparent Haptic Motion (AHM) illusion, temporal parameters are the most discussed for providing the smoothest illusion. Nonetheless, it is rare to see studies addressing the impact of changing these parameters for conveying information about the *velocity* of the elicited motion sensation. In our study, we investigate the discrimination of velocity changes in AHM and the robustness of this perception, considering two stimulating sensations and two directions of motion. Results show that participants were better at discriminating the velocity of the illusory motion when comparing stimulations with higher differences in the actuators activation delay. Results also show limitations for the integration of this approach in everyday life applications.

Keywords: Apparent Haptic Motion · Tactile speed · Tactile devices.

1 Introduction

Haptic illusions are a major tool to enhance tactile stimulations in a large variety of domains [12,11]. They are an interesting topic of research as they enable to convey rich sensations with rather simple stimulation techniques. One major illusion is the Apparent Haptic Motion (AHM) illusion. The apparent haptic motion illusion aims at conveying a sensation of continuous movement along the skin when only discrete points are stimulated. In his original work, Burtt [1] found that two distinct vibrotactile stimuli elicited in close proximity on the skin with overlapping actuation were not perceived as localized sensations but rather as a single moving vibration.

Studies regarding AHM were conducted on different body parts [13,8] to test its robustness and understand the essential parameters driving this sensory illusion. The illusion was demonstrated to be effective in conveying directional cues and proved to be robust in both 1D and 2D patterns [14], which suggests a potential for providing directional information during navigation tasks. Besides spatial parameters, i.e., the position of the activation points and their distance to each other, temporal aspects have also been studied, so as to deepen the understanding of the illusion mechanisms [9,15]. In this respect, some studies showed that the temporal parameters, i.e., activation delays between motors, were actually not strongly constrained. Indeed, Stimuli Onset Asynchrony (SOA) and Duration of Signals (DoS) that are different from those proposed by Sherrick and Rogers [16], can also efficiently elicit this illusion [8].

1.1 Speed perception and impacting parameters

Perception and discrimination of tactile speed has been studied in a large variety of conditions such as textures and vibrations [2]. These works mainly realized experiments with a surface sliding under the fingertip, creating a contact and skin stretch. Hence, the literature provides information on the influence of textures and vibrations on speed discrimination for different velocity ranges, going, e.g. from 33 to 120 $\mathrm{mm.s}^{-1}$ [3,6]. The results from [3,2] show that smooth surfaces are systematically felt as sliding slower than textured surfaces, even when presented with an identical sliding velocity. It was found that the Pacinian corpuscles have a crucial role in the discrimination of tactile speed [3], which explains the impact of material-induced vibrations on speed perception.

1.2 Speed perception of the apparent motion illusion

As previously mentioned, various studies confirmed the presence of the AHM illusion at different distances between the stimulation points (the position of the actuators) and with different SOA and DoS, deviating from the parameters indicated by Sherrick and Rogers [16]. Interest has been put to investigate various parameters regarding the spatial and temporal dimensions of the AHM illusion [9,13], enabling the creation of more complex and informative stimulations. Although other works have focused on determining the optimal actuation timing for conveying the most natural apparent motion, to the best of our knowledge, no study focused on the perception of speed and duration as a source of information in AHM. Understanding the parameters that make two stimulations easily distinguishable could indeed be relevant for tactile communication or navigation. For example, the speed perception of the apparent motion could help representing a moving obstacle or a safe direction to follow.

1.3 Contribution

The goal of this paper is to investigate the perception of the velocity conveyed during the AHM illusion. To go further, we also tested the robustness of this perception based on how the stimulation is provided. Indeed, while historically the AHM is conveyed with vibrations, our previous study [10] suggested that the illusion can also be conveyed by intervals of mechanical pressure. To explore that possibility, we conducted a study with two main objectives. First, we determine and compare the threshold of velocity discrimination for the apparent motion using both vibrations and pressure intervals ("taps") on the skin. Secondly, we study the impact of these modes on the participants' confidence when answering.

2 User study

This study aims to investigate the ability of discriminating a velocity change in the AHM illusion. The study has been approved by Inria's ethics committee (COERLE Dornell - Saisine 513).

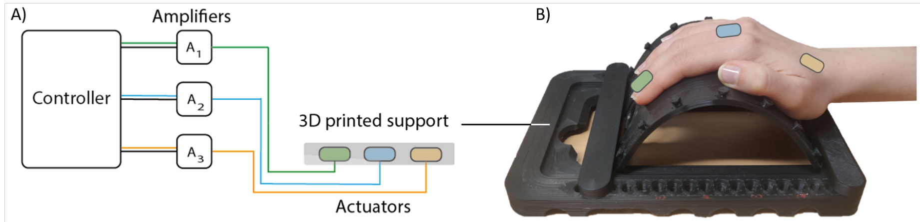

Fig. 1. Experimental set-up. A) The signals are generated via a controller and then amplified before being played by the custom-built actuators. B) Three electromagnetic actuators are placed on a curved hand-rest. The colored dots show the contact points of the actuators on the hand.

2.1 Experimental set-up and stimulation modes

The experimental setup is shown in Fig. 1. It is composed of three custom actuators inspired by the work of Duvernoy et al. [5], with a coil as a stator and two magnets glued together in their repulsive position as a mover to increase the magnetic field. The actuators are mounted onto a curved 3D printed hand-rest, positioned in a comfortable bend for the participants. The signals for the three actuators are first created with Matlab and then processed through a National Instrument USB-6343 series controller, which sends them to three amplifiers enabling to deliver a 6.5V signal to the motors, which corresponds to a force of approximately 0.4 N exerted on the hand. This last measure was recorded during a previous study, in which we characterized the force exerted by these actuators with a Nano17 force sensor (ATI, USA). The two magnets of the electromagnetic actuators move upward and downward along the center of the coil, depending on the electrical tension passing through it. This design enables to implement two stimulation modes: (i) a vibratory mode, where the actuators vibrate at 120 Hz, and (ii) a “tap” mode, where the magnets elicit a single impact to the user’s skin. The vibrating frequency for (i) was set based on previous studies investigating the apparent haptic motion illusion with vibrotactile stimuli, such as [17].

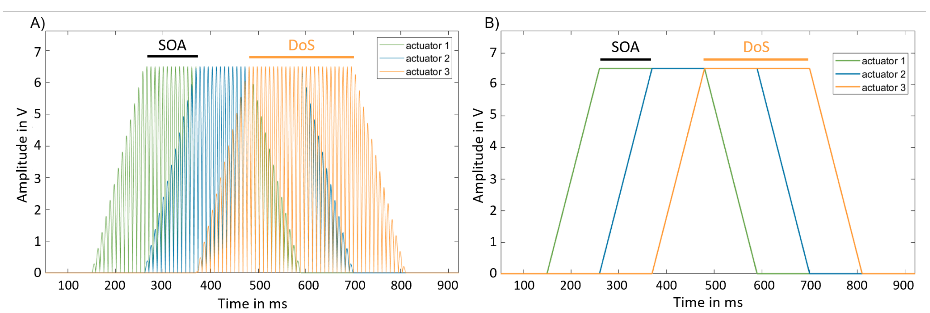

Fig. 2. Signals sent to the three actuators in the two actuation modes. A) Vibratory mode, made of sinusoïdal oscillations at 120 Hz within ramp envelopes. B) “Tap” mode made of single ramp signals. In this Figure, we used DoS = 220 ms and SOA = 110 ms.

Fig. 2 shows the signals imparted to the three motors in the two stimulation modes. In both modes, asynchronous overlapping stimulations are sent to the same three locations on the hand (see Fig. 1). While the duration of activation of the actuators is fixed, we seek to change the time delay between the actuators activation, also called Stimuli Onset Asynchony (SOA). Based on pilot tests and [7], we set $DoS = 220$ ms and the reference $SOA = 110$ ms in both stimulation conditions. In the following experiment, we tested SOA values of 90%, 80%, 70%, 60% and 50% of the reference SOA, making the comparison SOA values $[99,\ 88,\ 77,\ 66,\ 55]$ ms.

2.2 Experimental design

Stimulations are conveyed between the middle finger and the proximal part of the palm, as shown in Fig. 1. We consider the two stimulation modes presented in Sec. 2.1, vibratory and tap, as well as two directions of motion, proximal-to-distal (orange-to-green in Fig. 1) and distal-to-proximal (green-to-orange).

The two modes (vibrations or taps) are tested in two blocks, carried out one after the other. A block is thus made of only vibratory or only tap trials. Each block is composed of 80 trials of which the changing parameters are the SOA and the direction of the motion. A trial is a sequence of the reference signal with a SOA=110 ms and then a comparison signal with a different SOA, both having the same orientation (see also Sec. 2.3). The sequence of two signals is repeated a second time before the participants answer the questions. The order of the signal presentation is pseudo-randomized. Thus, blocks are only differentiated by the type of signal that is provided (vibratory or tap) and the order of the comparison, pseudo-randomized differently for each block and each participant.

2.3 Experimental procedure

Ten persons participated in the experiment. They were all between twenty-one and thirty years old, of which two were women, and one was left-handed. Stimulations were delivered on the dominant hand. Participants were naive about the hypotheses and process of the experiment. Participants carried out the experiment while wearing headphones playing white noise, so as to mask the sound coming from the motors. Indications about the global number of stimulations and questions were given before the experiment.

During a trial, participants would receiv, in a random order, (i) the reference stimulation ($SOA = 110$ ms), delivered with the stimulation mode of the block at hand, and (ii) one of the comparison signals having a different SOA, delivered with the same stimulation mode and same orientation. The identical sequence was played a second time to end a trial. After each trial, the participants answered two questions about what they perceived: (i) "Which one of the two motions was faster?" and (ii) "How certain are you of your answer?" The data collected from the participants were the index of the signal that seemed faster (1 or 2) and their confidence from 0 (no confidence at all) to 100 (total certainty). The mode of the starting block was counterbalanced between participants. At the end of the experiment, participants were also able to give open comments and feedback about their sensations and the experiment in general.

3 Results

Results are reported in Figs. 3 and 4. Fig. 3 shows the rate of correct responses (score), while Fig. 4 shows the reported confidence. These two parameters are the dependent variables of our statistical analysis. As independent variables, we report the results for five SOA levels and four experimental conditions: two directions of motion (proximal-to-distal or distal-to-proximal) and two types of stimulation (vibrations or taps).

Results showed a significant decrease of correct answers when the time delay between actuators, the SOA, increases and thus, gets closer to the reference SOA. This performance trend is observable in all conditions, both in taps and in vibration mode as well as with proximal-to-distal or distal-to-proximal direction patterns. To confirm the visual perception, we performed a Friedman statistical test on the four experimental conditions. The test highlighted the effect of the changing value of the SOA on the participants' performance to discriminate the fastest stimulation they received for the conditions of proximal-to-distal taps, distal-to-proximal taps, proximal-to-distal vibrations and distal-to-proximal vibrations ($p < 0.01$).

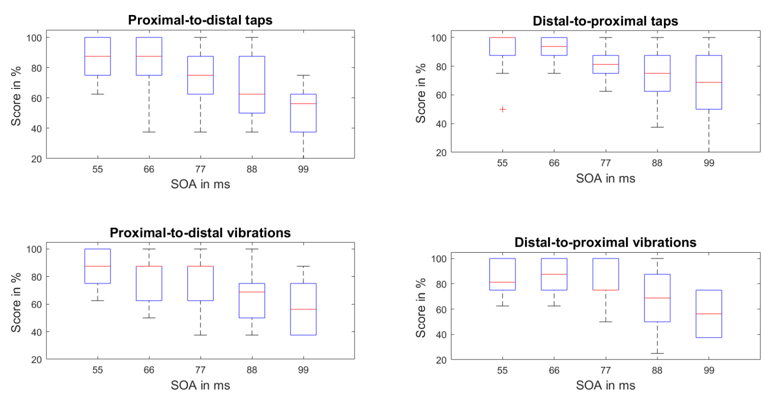

Fig. 3. Score when comparing five different SOAs vs. the reference one of 110 ms, across the two directions of motion (proximal-to-distal or distal-to-proximal) and type of stimulation (vibrations or taps). The boxplot gives the median, 25 and 75 percentiles with extrema values.

An identical Friedman test was performed on the effect the compared SOAs have on the confidence rates. A significant effect was also noted for the four experimental conditions ($p < 0.01$).

To interpret the effect of the direction (distal-to-proximal or proximal-to-distal) and the stimulation mode (tap or vibration), we performed matched-pairs Wilcoxon tests. The test showed no significant effect of the stimulation mode ($p > 0.05$) but it showed significant differences on the score between the proximal-to-distal and distal-to-proximal direction in tap stimulations ($p < 0.01$). However, a post-hoc test operated separately for each SOA did not show a significant difference for any of the comparisons.

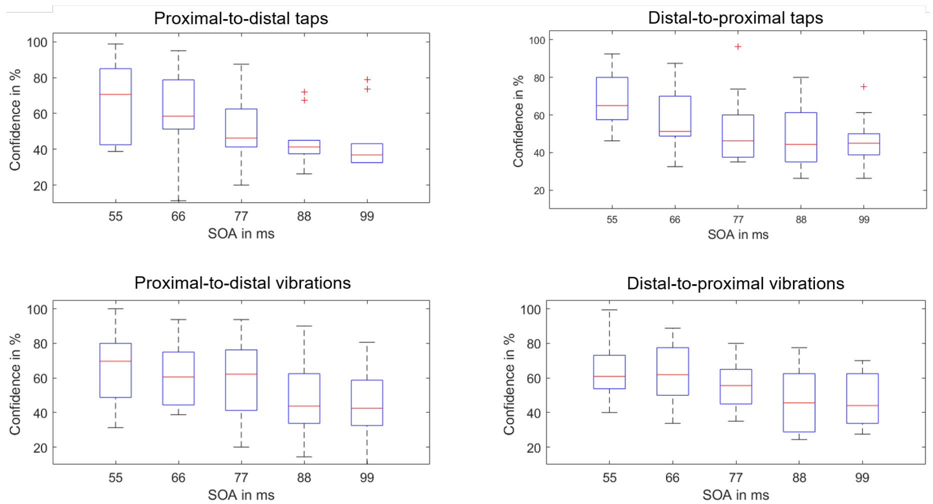

Fig. 4. Reported confidence of answer when comparing the SOAs, across the two direction of motion (proximal-to-distal or distal-to-proximal) and type of stimulation (vibrations or taps). The boxplot gives the median, 25 and 75 percentiles with extrema values.

Finally, the matching between performance and confidence was tested by a Spearman correlation test Fig. 5 and was found significant for all conditions, but with a rather low r coefficient of around 0.4.

4 Discussion and Conclusions

This paper investigated the perception of the velocity of the apparent movement as well as the impact of two experimental conditions: the direction of the AHM and the stimulation mode. We investigated two stimulation modes, standard vibrations and taps to the palm of the hand. We also considered two directions of motion, from the fingertip to the palm and vice-versa. We studied the role of the delay between the activation of the actuators in the perception of velocity As expected, the smaller the delay compared to the reference, the better participants' speed discrimination. However, it was surprising to observe performance around 85% even for the easiest comparison stimuli, for which the SOA was divided by a factor 2 compared to the reference. Another important objective was to determine the matching between participants' performance and their confidence. As expected, the confidence and score correlated but the r coefficient was surprisingly low suggesting that participants struggled to assess their own performance. There was no significant influence of the mode of stimulation on the

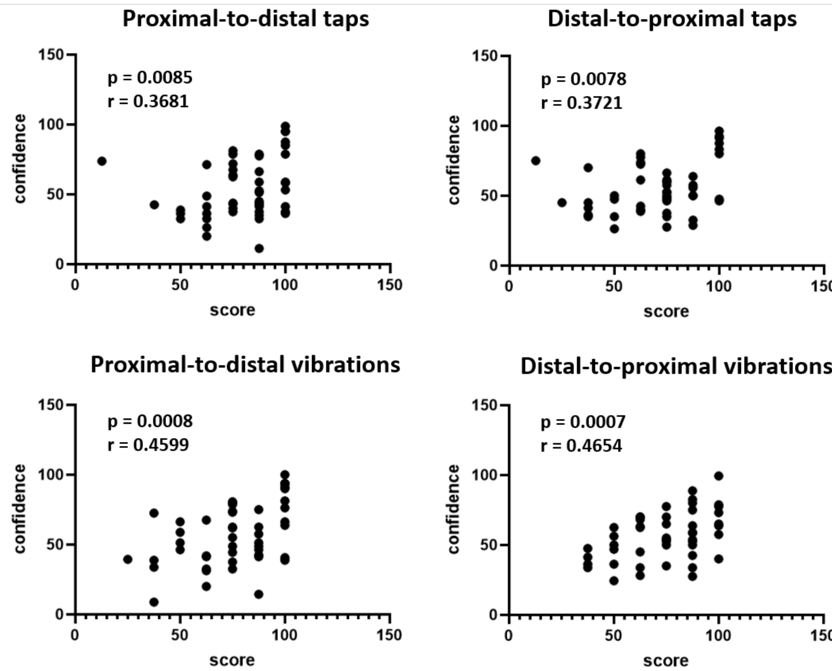

Fig. 5. Spearman correlation tests with the corresponding p-values and statistical dependence factors "r". We tested the correlation between the confidence and the score for the different conditions of mode and direction.

score or confidence, which showed a similar perception of both modes. Overall, the task was very challenging to participants and a few of them highlighted the difficulty of the task in their free comments. Thus, AHM illusions with different speeds might not be intuitive enough for people to use during everydat navigation tasks; the outcomes of the experiment were quite interesting in terms of haptic perception and confirm that human perception of tactile speed is inaccurate and prone to artefacts. The apparent haptic motion could still become a useful directional cue to integrate in navigation devices for impaired people, e.g., power wheelchairs, walkers, prewalkers [4] but modulating the speed might not be very informative. We wish to conduct further experiments, in which we let participants set what they perceive to be the best parameters for the AHM, e.g., duration, delay, intensity.

Acknowledgment

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References

1. Burtt, H.E.: Tactual illusions of movement. Journal of Experimental Psychology **2**(5), 371–385 (1917), place: US Publisher: Psychological Review Company
2. Dallmann, C.J., Ernst, M.O., Moscatelli, A.: The role of vibration in tactile speed perception. Journal of Neurophysiology **114**(6), 3131–3139 (2015)
3. Delhaye, B.P., et al.: Feeling fooled: Texture contaminates the neural code for tactile speed. PLoS biology **17**(8,) (2019)
4. Devigne, L., et al.: Power Wheelchair Navigation Assistance Using Wearable Vibrotactile Haptics. IEEE Transactions on Haptics **13**(1), 52–58 (2020)
5. Duvernoy, B., et al.: Electromagnetic Actuator for Tactile Communication. In: Prattichizzo, D., et al. (eds.) Haptics: Science, Technology, and Applications. pp. 14–24. Springer International Publishing, Cham (2018)
6. Dépeault, A., Meftah, E.M., Chapman, C.E.: Tactile speed scaling: contributions of time and space. Journal of Neurophysiology **99**(3), 1422–1434 (2008)
7. Gallo, S., et al.: Augmented white cane with multimodal haptic feedback. In: 2010 3rd IEEE RAS EMBS International Conference on Biomedical Robotics and Biomechatronics. pp. 149–155 (2010)
8. Israr, A., Poupyrev, I.: Control space of apparent haptic motion. In: 2011 IEEE World Haptics Conference. pp. 457–462 (2011)
9. Kirman, J.H.: Tactile apparent movement: The effects of interstimulus onset interval and stimulus duration. Perception & Psychophysics **15**(1), 1–6 (1974)
10. Lacôte, I., Pacchierotti, C., Babel, M., Marchal, M., Gueorguiev, D.: "Tap Stimulation": An Alternative to Vibrations to Convey The Apparent Haptic Motion Illusion. In: 2022 IEEE Haptics Symposium (HAPTICS). pp. 1–6 (2022), ⟨hal-03551830⟩
11. Lederman, Jones: Tactile and Haptic Illusions. IEEE Transactions on Haptics **4**(4), 273–294 (2011)
12. Lederman, S.J., Klatzky, R.L.: Haptic perception: A tutorial. Attention, Perception, & Psychophysics **71**(7), 1439–1459 (2009)
13. Niwa, M., et al.: Determining appropriate parameters to elicit linear and circular apparent motion using vibrotactile cues. In: World Haptics 2009 - Third Joint EuroHaptics conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. pp. 75–78 (2009)
14. Park, J., Kim, J., Oh, Y., Tan, H.: Rendering Moving Tactile Stroke on the Palm Using a Sparse 2D Array, vol. 9774 (2016), pages: 56
15. Sherrick, C.E.: Bilateral apparent haptic movement. Perception & Psychophysics **4**(3), 159–160 (1968)
16. Sherrick, C.E., Rogers, R.: Apparent haptic movement. Perception & Psychophysics **1**(6), 175–180 (1966)
17. Zhao, S., Israr, A., Klatzky, R.: Intermanual apparent tactile motion on handheld tablets. In: 2015 IEEE World Haptics Conference (WHC). pp. 241–247 (2015)