Mid-Air Ultrasonic Stimulations of the Palm - The Influence of Frequency and Stimulus Duration on Perceived Intensity

Driller, Karina; Frier, William; Pont, Sylvia; Hartcher-O'Brien, Jess

Publication date
2019

Document Version
Accepted author manuscript

Published in
World Haptics Conference, Tokyo, Japan

Citation (APA)
Driller, K., Frier, W., Pont, S., & Hartcher-O'Brien, J. (2019). Mid-Air Ultrasonic Stimulations of the Palm - The Influence of Frequency and Stimulus Duration on Perceived Intensity. In H. Shinoda , & H. Kajimoto (Eds.), *World Haptics Conference, Tokyo, Japan*

Mid-Air Ultrasonic Stimulations of the Palm - The Influence of Frequency and Stimulus Duration on Perceived Intensity*

Karina K. Driller[1], William Frier[2], Sylvia C. Pont [1] and Jess Hartcher-O'Brien[1]

***Abstract*— It is known that the duration of a short stimulus affects the perceived intensity of both visual, auditory, and, vibrotactile events, but it is still unclear whether such a relationship also exists for mid-air ultrasonic inputs to the hand. Here we investigate this issue and show how the perceived intensity of focused ultrasonic stimulations of the palm is indeed systematically related to stimulus duration - a relationship that is, however, independent of modulation frequency. This is an important finding for the overall goal of providing perceptually stronger inputs and enlarging the repertoire of realistic mid-air haptic experiences.**

I. INTRODUCTION

The ultrasonic phased array is a technology to successfully create contact-free, mid-air haptic experiences [1], [2] However, the resultant sensation is extraordinarily light and therefore provides a limited repertoire of haptic experiences. It is well established that the perceived intensity of short stimuli depends on their duration for both visual [3], auditory [4], and vibrotactile [5] events, which suggests an amodal perceptual metamer in which stimulus duration and intensity can be interchanged for the same perceptual outcome. However, whether such a relationship also exists for focused ultrasonic input, which on a mechanical level differs from contact-vibrotactile stimulation in terms of both friction cues and contact area, remains to be investigated. In addition, and although human tactile discrimination with respect to frequency is limited [6] the rendering frequency of airborne ultrasonic stimulation has been shown to modulate the sensation of mid-air interactions to some extent [2], [7], but whether this relates to perceived intensity remains unclear. Using a two-alternative forced-choice (2AFC) method and constant-stimuli procedure, we explore this relationship for three different modulation frequencies.

II. METHODS

A. Apparatus

The setup comprised a generic desktop computer with an audio channel that drove the ultrasonic phased array interface (UltrahapticsTM STRATOS Explore development kit). The focal point was set at 20cm above the array. Observers sat with their arm resting on an arm rest such that the ventral area of their hand was centered over the midpoint of the transducer array. The experiment was conducted in a sound attenuated room and observers wore noise canceling headphones, playing pink noise, to ensure that the feedback they received was purely haptic in nature.

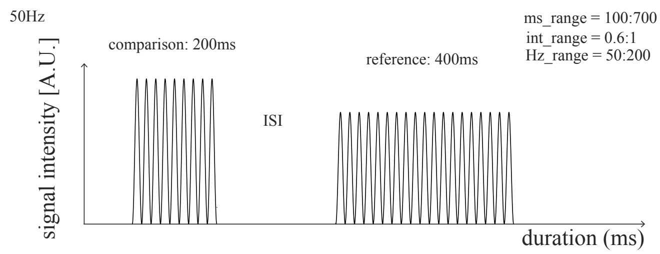

Fig. 1. Schematic representation of example trial.

B. Stimulus

The stimulus was generated at a sampling rate of 40000Hz. The stimulus (see Fig. 1), was an amplitude-modulation square-windowed sinusoidal wave, which provides an ultrasonic signal that can be detected on the skin. We manipulated the modulation frequency (50, 125 and 200 Hz), the duration (100-700 ms) and the intensity (60-100 %) of the stimuli used in the experiment. A 2AFC method of constant stimuli procedure was used to determine discrimination thresholds for ultrasound duration and intensity for a 400ms and 80% maximum-intensity reference stimulus.

C. Data Analysis

Proportion comparison stronger responses as a function of comparison stimulus duration and intensity were fit with a probit logistic function for each observer and stimulus frequency individually. Function fits for an example observer can be seen in Fig. 2 with each panel corresponding to each stimulus modulation frequency.

III. RESULTS

Figure 2 shows that a higher stimulus intensity was required for the stimulus to be felt as equally strong as the reference stimulus as the comparison duration decreases. This effect was present across all modulation frequencies and all observers. The point of subjective equivalence (PSE) represents the comparison intensity for which the two consecutive stimuli (reference and comparison) are in-discriminable. For shorter durations, the PSE clearly shifts to the right, indicating that higher intensities are needed for perceptual equivalence, suggesting that when identifying the strength

*We acknowledge the funding from the EU Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie Actions - Innovative Training Networks grant agreement H-Reality No 801413.

[1]K. K. Driller, S. C. Pont, and J. Hartcher-O´Brien are with the Delft University of Technology, Perceptual Intelligence Lab, Department of Industrial Design Engineering, Delft, The Netherlands. k.k.driller@tudelft.nl

[2]William Frier is with is with Ultrahaptics, Glass Wharf, Bristol BS20EL, UK.

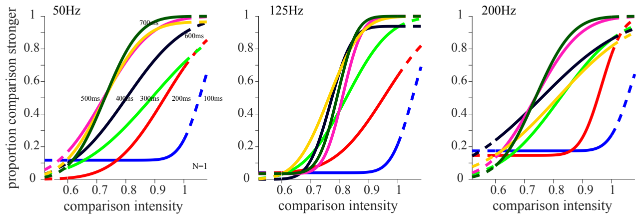

Fig. 2. Psychometric function fits for an example observer. Proportion comparison stronger responses are plotted as a function of stimulus intensity. Each column represents one of the modulation frequencies tested.

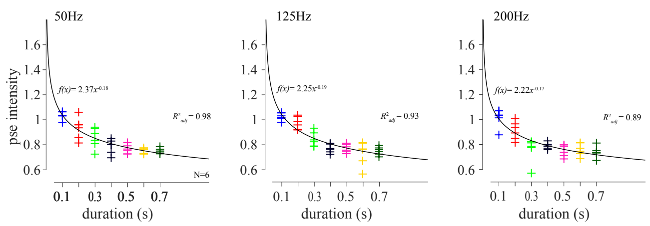

Fig. 3. PSE results. Individual participant intensity PSE values for each comparison duration plotted as a function of stimulus duration, with a power function fit to the group data for 50Hz (left), 125Hz (middle), and 200Hz (right).

of the ultrasonic inputs to the palm, duration and intensity can be interchanged.

As can be seen in Fig. 3, we observed a clear effect of stimulus duration on the perceived stimulus intensity, such that longer duration stimuli felt more intense than shorter duration stimuli. The effect was best described by a negative power law. However, no effect of stimulus modulation frequency was observed. The relationship between stimulus intensity and exposure time obeys a power law with a negative exponential term. The best fit was observed for the 50Hz stimulation pattern although no significant difference between fits was observed.

IV. Conclusions

We observed a duration-intensity metamer similar to that observed across vision, audition, and vibro-tactile inputs to the skin. A negative power law governs the processing of ultrasonic inputs to the palm. Thus, skin responses to ultrasonic inputs obey a temporal energy summation model and this mechanism is invariant to modulation frequency. The results provide guidelines with respect to one method of increasing user experiences of stimulus strength and altering the perceptual limits of ultrasonic phased arrays, which opens up possibilities for investigating more complex ultrasonic inputs in a controlled fashion. Future research might investigate additional temporal (summation) aspects such as click trains or rhythm of airborne ultrasonic stimulations as well as spatial summation.

References

[1] T. Hoshi, D. Abe, and H. Shinoda, "Adding tactile reaction to hologram," in *RO-MAN 2009 - The 18th IEEE International Symposium on Robot and Human Interactive Communication*, Sept. 2009, pp. 7–11.

[2] T. Carter, S. A. Seah, B. Long, B. Drinkwater, and S. Subramanian, "UltraHaptics: Multi-point Mid-air Haptic Feedback for Touch Surfaces," in *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology*, ser. UIST '13. New York, NY, USA: ACM, 2013, pp. 505–514.

[3] J. C. Stevens and J. W. Hall, "Brightness and loudness as functions of stimulus duration," *Perception & Psychophysics*, vol. 1, no. 9, pp. 319–327, Sept. 1966.

[4] B. C. J. Moore, B. R. Glasberg, and T. Baer, "A Model for the Prediction of Thresholds, Loudness, and Partial Loudness," *Journal of the Audio Engineering Society*, vol. 45, no. 4, pp. 224–240, Apr. 1997.

[5] S. Bochereau, A. Terekhov, and V. Hayward, "Amplitude and Duration Interdependence in the Perceived Intensity of Complex Tactile Signals," in *Haptics: Neuroscience, Devices, Modeling, and Applications*, M. Auvray and C. Duriez, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, vol. 8618, pp. 93–100.

[6] E. Gamzu and E. Ahissar, "Importance of Temporal Cues for Tactile Spatial- Frequency Discrimination," *Journal of Neuroscience*, vol. 21, no. 18, pp. 7416–7427, Sept. 2001.

[7] B. Dzidek, W. Frier, A. Harwood, and R. Hayden, "Design and Evaluation of Mid-Air Haptic Interactions in an Augmented Reality Environment," in *Haptics: Science, Technology, and Applications*, ser. Lecture Notes in Computer Science, D. Prattichizzo, H. Shinoda, H. Z. Tan, E. Ruffaldi, and A. Frisoli, Eds. Springer International Publishing, 2018, pp. 489–499.