The Influence of Amplitude and Sharpness on the Perceived Intensity of Isoenergetic Ultrasonic Signals

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I. Introduction

Several types of tactile stimulation have been proposed for surface displays [1]. One such technique, ultrasonic lubrication, enables modulation of the finger-surface friction. It has been shown that humans are very sensitive to subtle transient changes in friction [2], but little is known about how variations in the waveform of the ultrasonic vibration affect tactile sensation. Considering that summation mechanisms exist in touch, such as amplitude and duration of vibrotactile stimuli combining to provide the sensation of intensity [3] or both friction and normal force shaping the feeling of haptic pressure [4], there may be an interplay between the amplitude of the frictional change and the speed of the transitions from and back to the natural frictional state. This study investigates how humans perceive the magnitude of ultrasonic changes in friction that deliver an identical amount of energy to the finger through signals with varying amplitude and sharpness.

II. Materials and Methods

Nine ultrasonic signals were designed with three possible amplitudes (60%, 80%, and 100% of the maximum amplitude that can be delivered) and three possible transition durations at the start and end of the signal (6 ms, 8 ms, and 10 ms). To obtain signals that deliver the same amount of energy to the finger, the variations in amplitude were compensated by extending the duration of the signal (Fig. 1a), and sharpness changes were compensated by a slight reduction of the interval during which the waveform amplitude is maximal (Fig. 1b). The signals were delivered via a Hap2U Xplore Touch tactile display that was mounted on a Nano 17 force sensor (ATI, USA).

The task required the user to explore the haptic signals, which were co-located with a colored area on the screen (Fig. 1c). In each trial, the user was asked to rate the intensity of the signal on a scale from 1 to 9. Visual feedback helped them maintain the desired speed (7 cm/s) and normal force (between 0.2 N and 0.7 N). Each signal was repeated three times, resulting in 27 trials presented in a randomized order. Nine participants took part in this preliminary study.

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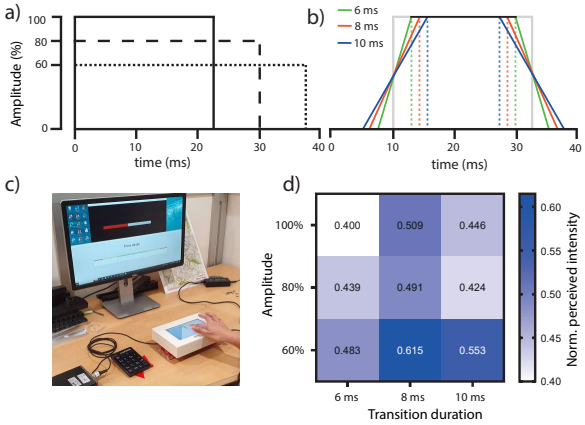

Fig. 1: a) Longer duration compensates lower maximum ultrasonic amplitude. b) The transition duration varies without changing the total delivered energy. c) Experimental setup. d) Normalized perceived intensity averaged across users.

III. Results and Discussion

A generalized linear mixed model (GLMM) analysis was performed on the participants' answers. It showed a significant effect of amplitude ($p = 0.028$), a marginal effect of transition duration ($p = 0.059$), and no interaction between these two variables ($p = 0.899$). Participants experience the frictional transient as more intense when the isoenergetic signal's amplitude is smaller, i.e., when its duration is longer. Surprisingly, the combination of the lowest amplitude and medium sharpness was felt as the most intense; duration seems to matter more than amplitude for intensity perception. The unexpected pattern for transition duration might come from the 6 ms transition being so sharp as to sometimes make the signal feel like two consecutive cues. However, additional measurements are needed to characterize each signal.

References

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