Design of pleasant vibrotactile stimulation through a seat

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***Abstract*—Vibrotactile stimulation to the gluteal or back regions through seats is a promising approach to deliver supplemental information to humans. Designing a method to achieve pleasant vibrotactile stimuli was addressed in this study, as such stimuli tend to result in unpleasant experiences for users. In particular, we investigated the properties of continual vibrotactile stimulation to the gluteal region through experiments and found that decreases in the duration of individual stimuli and vibratory frequency significantly increased the experienced pleasantness, whereas variations in the interval between consecutive stimuli exhibited no effect. Such principles are expected to generally hold in designing vibrotactile signals.**

I. Introduction

Tactile stimuli are an effective communication channel as an alternative to audiovisual stimuli. Vibrotactile stimuli have been used in a number of products and services because of their ease of implementation. In this paper, we investigate vibrotactile stimulation through seats. Some commercial products have employed such approaches, and further possibilities are being studied for integration with movie content [1] and automobiles [2], [3]. Most existing products and earlier studies have focused on how to effectively transfer information to users through vibrotactile stimuli.

There exists a common problem for vibrotactile stimulation. Vibrotactile stimuli easily result in unpleasant experiences, which are an unacceptable result for many products. Hence, pleasantness of the stimuli is as important as the quality of information delivered through them. In general, stronger stimuli lead to less pleasant experiences. When using seats, vibrotactile stimuli are presented to the gluteal or back regions, leading to a larger target area as compared to the hands or fingers, which are typically targeted by mobile information terminals. However, no general vibrotactile stimulation methods have been reported for restricting subjective unpleasantness while reliably transferring information. In order to address this issue, we experimentally investigated the subjective pleasantness of vibrotactile stimuli provided to the gluteal region through a seat while using stimuli that were strong enough to be nearly perfectly judged by the experimental participants.

II. Experimental apparatus

As shown in Fig. 1, eight recoil-type voice coil actuators (Haptuator Mark II, Tactile Labs., Canada, $9 \times 9 \times 32$ mm) were installed on a seat cushion. The cushion and vibrators were covered by a cloth sheet. The intervals between the neighboring actuators in a column and row were 5 cm and 20 cm, respectively. We used several vibrators displaced on a seat because typical applications make use of spatially distributed stimuli [1], [2]. Above approximately 50 Hz, the vibrator yielded stimuli strong enough for participants to perceive in our experimental setup.

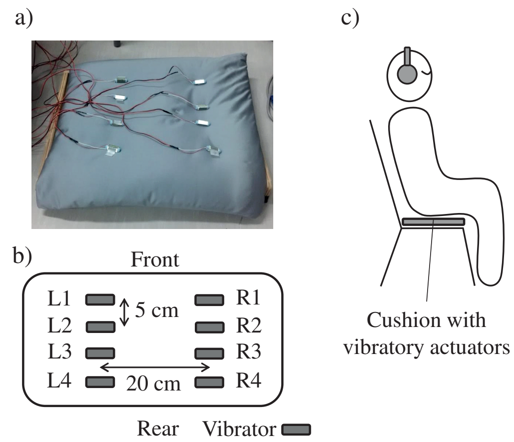

Fig. 1. Experimental setup. Cushion with eight recoil-type voice-coil actuators on a seat. Four actuators on the each of the right and left sides. a) Photo of the cushion and voice-coil actuators beneath a cloth sheet. b) Displacement of actuators on the cushion. c) Subject sitting on the cushion for experiment.

III. Experiment

A. Tasks

Individual participants sat on a seat with a cushion and vibrators. During the experiments, in order to mask visual and auditory cues, the participants closed their eyes and wore headphones playing a pink noise. The participants wore normal winter clothes. They responded on each trial on a 7-point pleasantness scale. The scale ranged from -3 (unpleasant) to 3 (pleasant), with 0 being neutral. Furthermore, in order to check how correctly the information was transferred to the participant, the participant answered whether the stimulation was on the left or right side.

B. Stimuli

In a single trial, a continual vibrotactile stimulus was presented to either the right or left side of the gluteal region. Four vibrators in the same column were simultaneously actuated. As shown in Fig. 2, the vibratory stimulus consisted of eight repetitions of short-unit vibration with frequency and period

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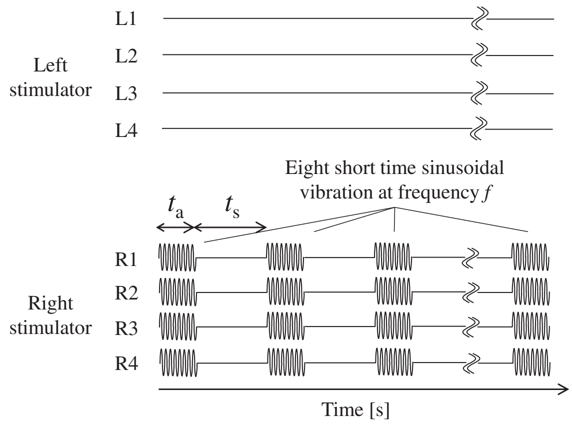

Fig. 2. Example of stimulation pattern where four right-side actuators are activated, and left-side actuators were still.

set to f Hz and t_a s, respectively. The interstimulus period was t_s s. These parameters took any of the following values: $f = \{50, 100, 150, 200, 250, 300\}$ Hz, $t_a = \{30, 45, 60\}$ ms, and $t_s = \{50, 100, 150, 200, 250\}$ ms. Although these values were arbitrarily determined by the experimenters, continual stimulation has been commonly used in other studies. Because of the mechanical properties of the vibrator, the acceleration of vibratory stimuli depended on the f value; however, for any f values tested in the present study, the stimuli were easily perceptible. The combination of the three types of parameters constituted 90 types of stimuli. Each of these stimuli was tested on the participant in randomized order. After a short break, a second session was conducted with the same participant. Hence, in total, 180 trials were performed for each participant.

C. Participants

Three university students who were unaware of the objectives of the study participated in the experiment after giving informed consent.

D. Analysis

We used all the trials for statistical analyses because the participants correctly answered the side of all presented stimuli. Given that there were minimal individual differences among participants, we pooled the results of all the participants after adjusting the mean response value of each participant to be zero.

In order to verify the linear effects of each parameter on the reported pleasantness values, we analyzed the results by using multiple regression analysis. The tested regression model was

$$P_{leasant} = a_1 t_a + a_2 t_s + a_3 f + a_0 \quad (1)$$

where $P_{leasant}$ and $a_{\{0,1,2,3\}}$ are 7-point pleasantness value and regression coefficients, respectively. For the analysis, we used the *stepwisefit* function provided by Matlab (Mathworks, MA).

IV. Results

From the analysis, the following model was acquired:

$$P_{leasant} = -0.012 t_a - 0.020 f. \quad (2)$$

This model indicates that a 1-ms increase of unit vibration period t_a decreases the pleasantness by 0.012 points ($p < 0.01$). Similarly, a 1-Hz increase of frequency f decreases pleasantness by 0.02 points ($p < 0.001$). The interstimulus period t_s did not have a significant effect. The R^2 value of the model was 0.51.

V. Discussion

The results and analyses indicated that shorter stimulus period (t_a) and lower vibratory frequency (f) lead to a more pleasant experience for the user. Because of the temporal summation effect of vibratory stimuli, longer vibrations are felt as stronger [4]. Furthermore, in the frequency range used in the experiments (50–300 Hz), higher frequency leads to stronger perception, with the peak frequency at approximately 250 Hz [5]. Therefore, decreasing the vibration period and frequency lessens the subjective strength of the stimuli. The decrease of subjective strength then leads to heightened pleasantness. These results are consistent with a report that stronger vibrotactile stimuli to the hands are likely to be disfavored [6]. Nonetheless, it is highly interesting that the properties of pleasant stimuli were experimentally demonstrated for large-area body parts like the gluteal region. From a methodological design perspective, it is recommended that the frequency of vibration remains small when the unit vibration is longer, and vice versa.

VI. Conclusion

In experiments presenting vibrotactile stimuli to the gluteal region of human participants on a seat, we investigated the factors of stimuli to limit the discomfort experienced by users. It was found that decreasing the period and frequency of vibratory stimuli is effective for achieving pleasant stimuli. Contemplating the generality of the stimuli used in the present study, this can be a guideline applicable to various applications.

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