Vibrotactile Stimuli are Perceived More Intense at the Front than at the Back of the Torso

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Abstract. Vibrations effectively transmit information from objects, surfaces or events to the human skin through the cutaneous sense. However, due to the diverse densities of receptive fields and mechanoreceptor populations vibrotactile sensitivity differs across body parts. Hardware that utilizes vibrotactile information should consider such differences. Here, we examined perceived intensity of vibrotactile stimuli applied to the front and back of the human torso. Participants wore a vibrotactile vest. They had to judge if a vibration from the back side of the vest was larger or smaller than a fixed vibration given from the front side; the intensity of the stimulus at the back was adapted using staircase methods. We found that, stimuli at the back had to be physically more intense by 12.3% than stimuli at the front to be perceived equally intense: Presentation of vibrotactile information through wearables could equalize for differential sensitivity, e.g., to equalize attention-capturing effects.

Keywords: Vibrotactile Perception, Human Torso.

1 Introduction

The human cutaneous sense receives information on object properties and events in the environment through skin contact. Vibrations provide one important way to transmit information–being elicited, e.g., through movement across textures, fast contacts with objects or artificial sources. Haptic displays such as vests use this sensory channel by transmitting vibrations to the skin [1]. Specialized mechanoreceptors in the skin gather information: Pacinian Corpuscles (PC) are highly responsive to vibrations, in particular to frequencies above 40 Hz. Their sensitivity achieves its peak around 200-300 Hz. Also, rapidly adapting (RA) Meissner receptors contribute to the perception of vibrotactile stimulation in lower frequency ranges below 100 Hz [2]. Vibration sensitivity can differ between body parts, e.g., between upper and lower leg, indicating differences in perceived intensity [3, 4]. Knowledge on perceived intensity can improve the design and use of vibrotactile garments by guiding actuator choices and allowing to equate perceptual effects across the body. Here, we studied perceived intensities of vibrations at front versus back of the torso in the context of haptic vest design.

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2 Methods

15 participants (8 female; age range: 21-25 years; *M* = 23.1; *SD* = 1.3) participated in the experiment (none reported sensory impairments). Participants provided written informed consent prior to the experiments. An already available vibrotactile vest, bHaptics TactSuit X40 (40 Eccentric Rotating Mass actuators with vibration frequency ~ 90 Hz), was used. The vest was tightly fit to the body equally both at the front and the back with straps. Using one actuator at each time point (four in total), we gave vibrotactile stimulation for 300 ms on the front or back of the torso at height of the upper middle chest (Fig. 1B). Active noise cancelling headphones (Sennheiser Momentum 3) plus white noise masked actuator sounds. We used the adaptive staircase method to estimate points of subjectively equal vibration intensity (PSEs) at the back side of the torso as compared to the front side. In a within-participant design, fixed *front intensity* levels of vibration (acceleration) amplitude in different blocks were 11.3, 12.9, and 14.5 m/s^2 root mean square [5]. Stimuli were given either at the left or the right *body location* (two different sessions, order balanced). Each trial started with a vibration at the front, followed by a 100 ms interstimulus interval, and then a vibration at the back. Participants indicated whether the intensity at the back was larger than at the front. In each staircase, back intensity was reduced by 1.4% after a 'yes'-response in the previous trial and increased after 'no'. If a participant responded oppositely in 2 consecutive trials, it was considered a reversal. Each staircase stopped after 6 reversals or after 100 trials (average staircase length: 55 trials). PSEs were calculated as the average back intensity at the last 3 reversals. Each block comprised randomly interleaved trials from 6 staircases (starting at front intensity +44% or +24%)

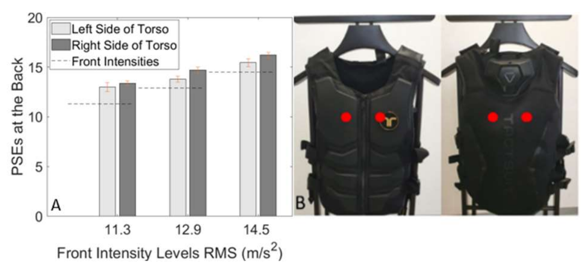

Fig. 1A. PSEs at the back as a function of *front intensity* and *body location*. Error bars represent standard errors. **1B.** Vibrotactile vest and the actuator locations used in the experiment.

3 Results

We calculated condition-wise individual average PSEs (Fig. 1A). *t*-tests between PSEs at the back and the physical front intensities (2 body locations x 3 front intensities) were significant, each $t(14)>15.7$, $p<.001$ (Bonferroni-corrected), showing that physical intensities at the back need to be higher than at the front to be perceived equal. Further, a repeated measures ANOVA compared PSE values between different conditions. As expected, there was no significant main effect of *body location*, $F(1, 14) = 2.7$, $p = .122$, nor a significant interaction with *front intensity*, $F(2, 28) = .9$, $p = .40$, but a significant main effect of *front intensity*, $F(2, 28) = 184.9$, $p < .001$. Follow-up *t*-tests for pair-wise comparisons (Bonferroni-corrected) were significant, indicating that PSEs at the back were larger for higher front intensities.

4 Discussion

Here, we investigated the perceived intensity for vibrotactile stimuli applied at the front of the human torso as compared to the back. The front torso turned out to be clearly more sensitive: Physical intensities at the back had to be higher by 12.3% than at the front to be perceived as being equally intense. The difference was observed both in the left and right side of the body. Similar sensitivity differences between front and back were found for spatial acuities for point stimuli [6]. Such sensitivity differences may indicate differences in mechanoreceptor distributions between front and back.

Knowledge on differences in perceived intensity across the body can be beneficial in vibrotactile vest design and use. Finding suggest, e.g., that less intense actuators are needed in the front of the torso as compared to back. Also, attention-capturing effects of vibrotactile stimuli are known to increase with intensity [7]. Considering differences in perceived intensity could be used to capture attention at different body sites in equalized and precise ways. Here, however, we only investigated the PSEs of two locations at the back. Moreover, data may have slight bias because we had a fixed order of front and back stimulation and initial back stimuli were higher than in the front. Further studies are required to precisely model perceived differences on different body locations.

We conclude that stronger vibrations need to be given to the back of the torso in order to match vibrotactile sensations at the front. Haptic rendering displays could benefit from equalizing the perceived intensities, e.g., in attention capturing.

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