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The Effect of Weight on the Perception of Vibrotactile Intensity with Handheld Devices

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Abstract

The objective of this study was to determine whether the weight of a vibrating handheld object influenced the perceived intensity of its vibrations. Experiments were conducted to determine the subjective equivalence of vibrotactile intensity for objects that had the same size but had different weights. The results suggest that for the same surface acceleration and hence the same movement, the heavier is the device, the stronger is the perceived intensity.

1 Introduction

Vibrotactile signals are nowadays important for the design of a variety of handheld devices. To design them, it is important to know whether the perceived vibrotactile intensity depends on other object attributes, chiefly among them is weight. Despite a long history of vibrotactile studies we could find little data that was related to this question [1, 4–6, 8].

Most portable phones provide a vibrotactile function to signal a call. Design engineers must carefully select the actuator to fit a tight power budget. We observed however that the way a device felt in our hand seemed to depend on its weight, and this despite compensating for the physics of vibration. This led us to hypothesize the existence of a weight-vibration perceptual interaction.

We carried out an experiment to determine the subjective equivalence of the vibration intensity for objects having different weights. We found that for the same acceleration, doubling the weight of an object resulted a perceptual sensitivity enhancement of about 2.4 dB.

2 Method

We manufactured boxes with weights and sizes similar to that of common portable phones. Each was equipped with a high-bandwidth actuator and an accelerometer attached to its surface. The method of adjustment was used whereby participants adjusted the vibrating intensity of a given box to match that of a reference box.

Apparatus. Four boxes (80 × 40 × 17 mm), along with their controlling circuitry, were made. The boxes weighted 50, 110, 200 g. A fourth 110 g box served as the reference. Each contained a custom-made, recoil-type Lorentz actuator made of a magnet suspended inside a pair of coils in an open magnetic circuit arrangement. It could accelerate a 110 g box up to 30 m/s^2 from 20 to 500 Hz with minimal distortion. The intensity was adjustable by turning a rotary control similar to that of audio equipment. Each had a calibrated accelerometer (MMA7260Q, Freescale).

Stimulus. We used sinusoidal vibrations of 150 Hz with amplitudes from 3 to 14 m/s^2. The signals were pulsed in a 0.5-second-on, 0.5-second-off duty cycle to minimize adaptation. The frequency, magnitude and the pulse-train signal approximated that of an actual a portable phone.

Protocol. Eight healthy university students (4 males, 4 females) were recruited. During each session, the participants were seated in front of the four boxes which rested each on a block of soft gel. They were told that there was one reference box and 3 adjustable boxes. For each trial, the reference box and one of the tunable boxes would vibrate. They had to lift, feel the boxes, and then adjust the intensity of the tunable box until its vibration felt the same as the reference box. They wore sound-blocking earphones and used their dominant hand only. When a participant was satisfied, she put both boxes back on their block of gel. The acceleration of each box was recorded and logged by computer before the next trial. Each participant was presented 20 pairs of stimuli in total, and they were asked to take a one-minute break after the 12th pair. All completed the experiment within 30 minutes.

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3 Results

The results (acceleration r.m.s. converted to dB re 10^{-6} m/s^2), see Fig. 1, showed that the weight of the device influenced the perception of vibration magnitude. The data for each condition was fitted with straight lines. The control condition was when participants had to match intensity of boxes of same weight. On average, they behaved almost like the ideal performer (thick line) for this condition. We calculated the normalized acceleration by taking the ratio of the matched acceleration over the reference acceleration. The ANOVA test performed for each of the three pairs of data (50 g vs 110 g, 110 g vs 200 g, 50 g vs 200 g) showed significant difference for all the pairs ($p < 0.001$). On the boxplot, the notch indicates a robust estimate of the uncertainty about the medians for box-to-box comparison. Since the notches do not overlap, the plot indicates the medians of each pair differ at the 5 % significance level. The results show that a heavier box requires less acceleration to produce the same perceptual effect than a lighter one.

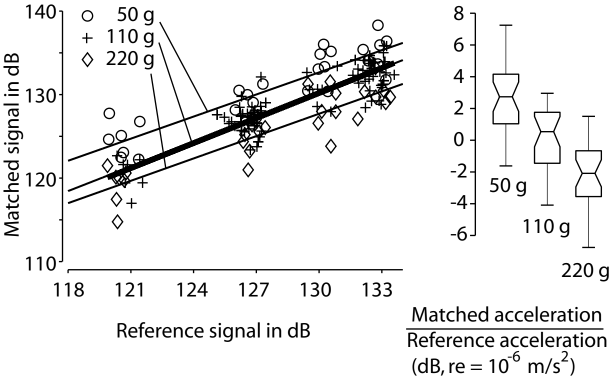

Figure 1. Matched values vs reference values.

4 Discussion

Our results support the hypothesis that the weight of an object affects the perception of vibration magnitude. The heavier the box, the smaller is the required acceleration to produce the same perceptual intensity. One possible explanation is that when we hold a heavy box in our hands, we need to use a stronger grip, therefore the contact area between the skin and the device is larger than with a lighter box [7], which, in turn, stimulates a larger number of mechanoreceptors. A second explanation is that a heavier object can cause more tissues to vibrate for the same acceleration. A third explanation would appeal to psychophysical mechanisms [3]. Whatever the biomechanical, neurophysiological, or psychological factors may be, our nervous system translates this vibration pattern into the perception of stronger intensity.

The weights were specifically selected to have almost the 1:2:4 ratios. As seen in Fig. 1, the relative perceptual differences between the successive weights are almost the same: 2.4 dB between 50 g and 110 g, and 2.3 dB between 110 g and 200 g. This difference was relatively constant for all signal amplitudes within our range of testing. This means that, on average, for the range of weight between 50 and 200 g, to obtain the subjective equivalence for a device twice as heavy, one need to reduce by about 2.4 dB to the response of the original box.

5 Conclusion

We have found that the design of the vibrotactile signal given by a handheld device should take its weight into consideration. This result is potentially useful for the portable device industry as it provides a basic guideline for vibrotactile tactile transducers.

It tempting to relate our findings to the well-known size-weight illusion [2]. Our present protocol makes an implicit causal connection between weight and the perception of vibrations as it is motivated by our application. It would be interesting to investigate whether a reverse interaction occurs.

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