Strap Tightness and Tissue Composition Both Affect the Vibration Created by a Wearable Device

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I. Introduction

Wearable haptic devices can provide salient real-time feedback (typically vibration) for rehabilitation, sports training, and skill acquisition. Although the body provides many sites for such cues, the influence of the mounting location on vibrotactile mechanics is commonly ignored. This study builds on previous research [1] by quantifying how changes in strap tightness and local tissue composition affect the physical acceleration generated by a typical vibrotactile device.

II. Methods

We rigidly attached a Precision Microdrives C10-100 linear resonant actuator (LRA) to a 3D-printed housing with a curved concave plate that rests on the skin. An inelastic hook-and-loop-fastener band was used to tighten the housing against the limb. An IIS3DWB three-axis accelerometer sampling at 27 kHz was mounted onto the LRA to capture normal acceleration. A TI DRV2605L motor driver was used to control the LRA to vibrate at 175 Hz for 150 ms.

We attached the housing to the shank of a healthy participant and collected acceleration data at the four sites shown in Fig. 1. The strap was manually adjusted to three levels of tightness. Three recordings were collected for each combination of site and tightness, resulting in 36 total data points. Acceleration data were post-processed to compute average peak-to-peak acceleration during steady-state vibration. We conducted a two-way ANOVA with site and tightness as factors and peak-to-peak acceleration as the dependent variable. We hypothesized that higher tissue stiffness and increased strap tightness would decrease vibration magnitude and that differences due to tissue stiffness would become less pronounced with increasing tightness.

III. Results and Discussion

As shown in Fig. 1, the vibration magnitude decreased as the strap was tightened, likely due to the actuation of the housing being restricted as the skin and muscle were compressed against the underlying bone. We observed a significant effect of tightness on vibration magnitude ($F(2, 24) = 53.0, p < 0.0001$). The next version of this wearable device will include force-sensing capabilities to standardize mounting across users. Nonetheless, this finding that tightness affects vibration magnitude highlights the importance of considering both user comfort and vibration mechanics when using wearable haptic devices.

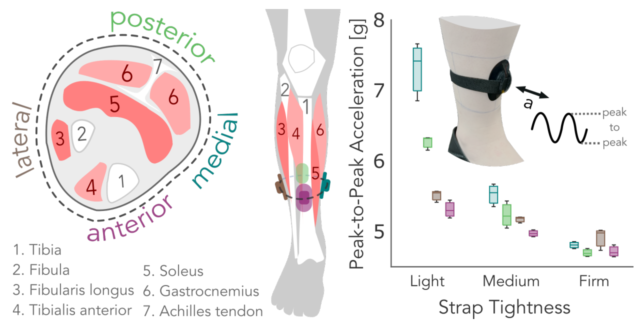

Fig. 1. The bones, muscles, and tendons of the shank dictate its composition at the medial, posterior, lateral, and anterior sites. Measurements on one user showed that mounting location and strap tightness significantly influence the peak-to-peak vibration generated by a typical wearable haptic device.

The composition of the tissue itself strongly influenced vibration magnitude at similar levels of strap tightness. We observed a significant effect of site on vibration magnitude ($F(3, 24) = 9.3, p = 0.0003$). Whereas the medial aspect of the shank had the greatest magnitudes due to the high compliance of the gastrocnemius and soleus muscles, attaching a vibrotactor in the anterior location near the tibia limited vibration magnitude due to the rigidity of the bone. It is important to note that differences in muscle geometry and tissue properties across individuals can be profound, and our findings are limited to a single sample. However, the relatively greater thickness of medial muscles compared to anterior muscles suggests that the underlying principles are likely to be robust.

The effect of strap tightness on vibration magnitude was site-dependent. There was a significant interaction between tightness and site ($F(6, 24) = 4.1, p = 0.006$), where tissues with higher compliance were more sensitive to changes in tightness. While we need to investigate how these mechanical differences translate into perceptual differences, our results represent a step toward establishing a comprehensive psychophysical characterization that will aid haptic designers in understanding how device design and underlying musculoskeletal structures may impact vibration feedback.

References

[1] M. Azadi and L. A. Jones, "Vibrotactile actuators: Effect of load and body site on performance," in *Proceedings of the IEEE Haptics Symposium (HAPTICS)*, 2014, pp. 351–356.

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