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Evaluating Perceptual Characteristics of Impact Haptic Stimuli

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I. Introduction

Impact haptic sensation, induced by a physical collision inside the actuators, has emerged in current applications including multimodal, immersive VR experiences [1]. While push-pull solenoids are often used to create such sensations [2], there are efforts to develop miniature actuators with intense feedback [3]. Interaction scenarios that require imminent, intuitive feedback or those with collisions between objects could benefit from the sensation [1]. However, how we can express the impact haptic sensations *in verbal expressions* has not been explored, compared to studies on vibrations [4], [5]. Therefore, we introduce our ongoing study that investigates expressions of impact haptic sensations by conducting a series of user experiments, including vocabulary collection, subjective ratings, and stimulus-expression matching. The protocols were approved by the IRB of the author's institution (HYUIRB-202411-024-1).

II. User Study

A. Apparatus and Setup

We used two types of linear magnetic actuators (TITAN Haptics; a Tachammer Drake LFi and a Tachammer Carlton, with maximum intensities of 19 G and 25 G) attached to a cloth glove (Fig. 1). Three Drake LFi actuators were attached to the fingertips of the thumb, index, and middle fingers, and a Carlton actuator was attached to the thenar eminence. The actuators were controlled via L298 motor drivers connected to a computer with a DAQ (National Instruments; PCIe-6323), and measurements were done by a miniature triaxial accelerometer (Kistler, 8766A). Participants sat at a desk and wore noise-canceling headsets and the glove on their nondominant hand (see Fig. 1.)

As stimulus locations, we selected two: fingertips and the thenar eminence, which are the main areas involved in hand-on interactions. The amplitude of impact stimuli was set to the maximum (19 and 25 G), with four different driving frequencies of 2, 5, 10, 20 Hz. We also selected duration as another design parameter; three durations (0.2, 0.5, 1.0 s). As a result, a total of 24 conditions were derived.

B. Stimuli

C. Exp. I: Adjectival Expression Collection

Given that adjectival expressions regarding impacts were barely explored, we started our study by gathering the expressions from the participants.

1) Participants: 12 university students (3 male, 9 female; 22-28 years old, average of 24.33) without any known sensory disorders participated in this study. They received 10,000 KRW (about 8 USD) as compensation.

2) Procedure: In each session, 24 stimuli were given to the participants one by one, in random order. Participants were asked to freely describe their sensations regarding the stimuli verbally. These responses were recorded, and the results were collected through a speech-to-text (STT) process. A session lasted about 15 minutes, and three sessions per participant were conducted.

3) Results: We counted the frequency of verbal expressions in the transcribed texts across the participants, after postprocessing of the raw data such as spell correction. We observed a consistency in the results from fingertips and thenar eminence stimuli. Fingertip stimuli were associated with expressions related to *weight* were mentioned 44 times, *roughness* 39 times, and *hardness* 25 times. Regarding the thenar eminence stimuli, *weight* was mentioned 60 times, *roughness* 59 times, and *hardness* 60 times. Other expressions, such as intensity, rhythm, elasticity, and metaphors involving interaction with specific objects, also appeared, but fewer than 10 times. Thus, to encompass sensations in both fingertips and palm (thenar eminence), we selected *roughness*, *hardness*, and *weight* for the initial rating experiments.

D. Exp II: Adjectival Rating

1) Participants: 20 university students (9 male, 11 female; 21-28 years old, average of 24.05) without sensory disorders participated in this study. The same amount of compensation as in Exp. I was given.

2) Procedure and Data Analysis: A standard magnitude estimation with free modulus procedure was used [6]. In each trial, the stimuli from the 24 combinations were selected. Participants evaluated the given stimuli with the given verbal expressions using a positive number in their own scale. Three

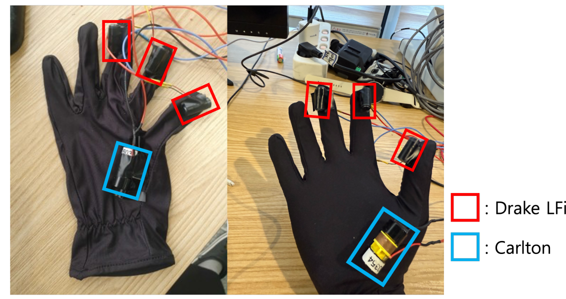

Fig. 1. The glove equipped with impact actuators used in this study

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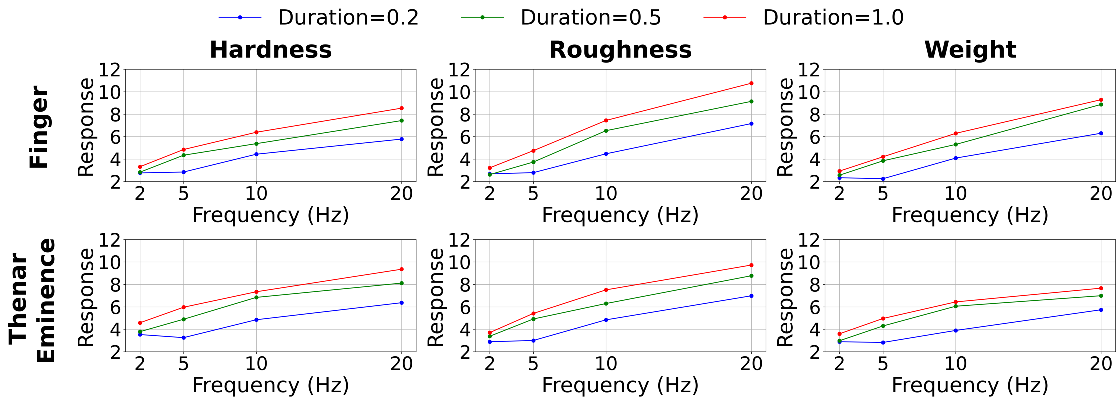

Fig. 2. Adjective Rating results of Impact Sensation.

sessions, each consisting of 24 trials, were conducted per participant. The overall procedure took about 40 minutes.

3) Results: For data analysis, we discarded the results from the first session, treating it as a tutorial. Then, we normalized the results by following a standardization procedure [6]. Fig. 2 depicts the normalized ratings. For stimuli with relatively longer duration (0.5 and 1 s), the ratings generally increased as duration and frequency increased, suggesting that the stimulus energy given to the skin was associated with the ratings. For short duration (0.2 s), less than 10 Hz, the trend was unclear, given that only one to five hits appeared on the user's skin. The variance of ratings may be associated with the expressibility–wider range indicates higher perceptual resolution aligned with the expression.

E. Exp. III: Brief Validation of Stimuli–Score Mapping

1) Participants: 20 university students (7 male, 13 female; 22-28 years old, average of 24.1) without sensory disorders participated in this study. The same amount of compensation to the Exp. I was given.

2) Procedure: We divided the 24 stimuli into five-point ratings for each of the adjectives based on the adjectival rating results of Exp. II. For example, if a stimulus received the 3rd highest roughness rating (of 24) and 10th in weight, assigned roughness and weight scores would be 5/5 and 3/5, respectively. In each trial, participants rated the degree of agreement between the given stimulus and adjectival score on a 0-100 scale.

3) Results: Similar to Exp. II, the first set was treated as a tutorial and excluded from the results. Fig. 3 shows that the participants' overall degree of agreement ratings on the score. Participants generally agreed (scores over 80) for the mapping between stimuli and adjectival scores, although considerable individual differences were observed.

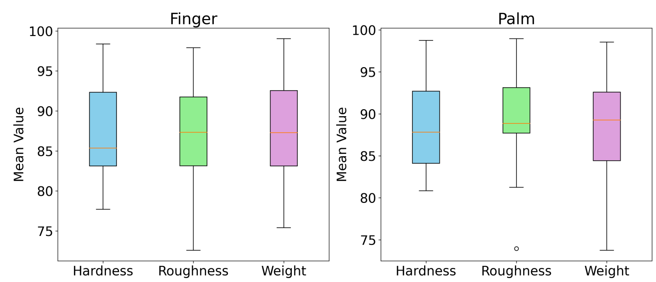

Fig. 3. Individual Average Degree of Agreement on Adjective Scores

III. Summary and Ongoing Work

In this work, we collected and evaluated adjectives quantitatively related to impact sensations to understand how users express underlying perceptual characteristics verbally. We derived a few adjectival ratings, such as roughness, hardness, and weight to express impact haptic sensation. Then, we mapped the stimuli and expression scores and evaluated their degree of agreement via a separate user study to confirm the reliability of the relationships derived in this study. From the results in Exp. II and III, we found: 1) participants can rate longer, repeated impact stimuli, as done for vibrations, and 2) participants generally recognize the association in adjectival rating scores and the sensation of stimuli. Based on the current effort, we are developing an AI-driven multimodal haptic authoring system that generates haptic feedback utilizing the results of this work, to support the creation of personalized and intuitive haptic content. We ultimately aim for a context-aware automated system that provides immersive multimodal haptic experiences involving interactions with virtual objects.

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