Can the Sense of Heaviness Be Altered to Feel Lighter through Tendon Vibration? *

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***Abstract*— The kinesthetic illusion is a movement illusion of one's own body. While this illusion has been mainly explored to elicit illusory body movement, it can also present proprioceptive feedback, such as the sense of heaviness of virtual objects. In this paper, we preliminarily investigated whether this illusion could increase/decrease the sense of heaviness while lifting weights. The results from the two participants suggest that the sensation can not only become heavier but also lighter.**

I. Introduction

Many researchers have developed haptic feedback techniques employing visual or tactile illusions (e.g., pseudo-haptics) for virtual reality (VR) experiences. Among these, the kinesthetic illusion, one type of proprioceptive illusions, is induced by applying vibration to muscles and tendons [1]. This illusion is caused by the vibration-based modulation of the firing rate of muscle spindles, which play a crucial role in sensing limb position and movement. This illusion has been explored to understand kinesthetic perceptions [1].

Recent studies demonstrated that muscle spindles contribute to the sense of heaviness [2], thus the kinesthetic illusion has the potential to be used as proprioceptive feedback (e.g., for heaviness) during interactions with virtual objects.

We previously reported that applying tendon vibration to the wrist and elbow during lifting movement could *increase* the sense of heaviness [3]. In this paper, as a next step, we preliminarily investigated the effect of the illusion on *decreasing* the sense of heaviness with a modified setup. With a result from two participants, we suggest that the sense of heaviness is not only increased but also possibly decreased by the kinesthetic illusion.

II. Methods

While the primary purpose of this study is to explore whether the sense of heaviness can be decreased, a stimulation condition to increase heaviness was included. We targeted a movement around the shoulder while holding up an object (i.e., a larger arm movement), which involves a larger number of muscles than our previous report [3], and thus, the illusion induced by multiple muscles might become clearer.

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A. Tendon Vibration on Wrist, Elbow, and Shoulder

As shown in Figure 1, we placed vibration actuators (Acouve Lab, VP210) on the anterior and posterior sides of the wrist, elbow, and shoulder. A pressure sensor (Interlink Electronics, FSR 402) was laid on the tip of each actuator to roughly observe the loading force on the body. We delivered vibratory stimulation to multiple joints to strengthen the illusion and ensured that the participants felt the illusion [1], [4]. We applied 70-Hz vibration at 70 m/s^2 at each stimulation site. These parameters were designed based on prior literature [1].

B. Apparatus

A six-point vibratory stimulation setup was achieved using an audio interface (Roland, OCTA-CAPTURE) coupled with three stereo audio amplifiers (FX-AUDIO-, FX202A/FX-36A PRO). The vibration signals were generated through audio-programming software (Cycling '74, Max 8).

As a method to enable the participants to feel heaviness with consistent tactile information and lifting movement, we created pulley equipment shown in Figure 2. The grip consisted of a 3D-printed hollow cylinder (30-mm diameter and 150-mm length) tethered to the weight using a thread (RUNCL PowerBraid, 90lb, 0.5 mm) through pulleys.

C. Conditions and Procedure

The participants lifted weight samples using their left and right arms with two sets of pulley equipment and compared the sense of heaviness between the two weights. We adopted both-arm lifting to make the comparison easier. To leverage the effect of tendon vibration on each joint, the participants were asked to lift a weight by shoulder movement while

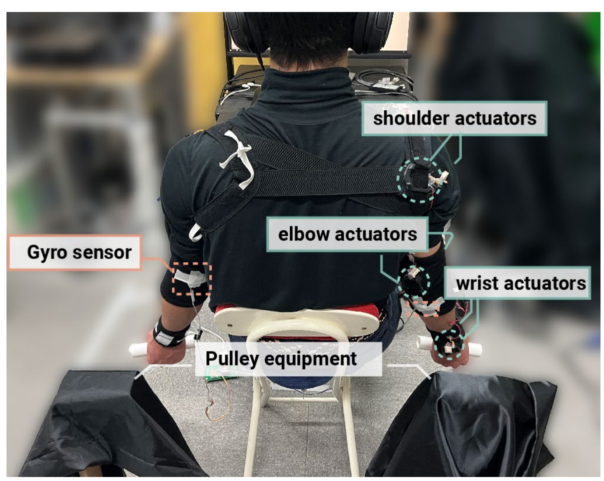

Figure 1: Overview of experimental setup. Vibration actuators were arranged on both anterior and posterior sides.

maintaining elbow and wrist joints straight.

There were three stimulation conditions: no vibration, anterior vibration, and posterior vibration. In the anterior vibration and posterior vibration conditions, vibrations were applied to each joint's anterior or posterior side (i.e., muscles responsible for flexion or extension, respectively), aiming to increase/decrease the sense of heaviness. In stimulation conditions, vibration was constantly applied on the same side during lifting based on an intention to enhance/reduce a gravity effect on the weights.

The experiment procedure followed the method of constant stimuli. We established 300 g as a reference and prepared nine weights for comparison from 100 g to 500 g in 50-g increments (i.e., 100, 150, 200, 250, 300, 350, 400, 450, and 500 g). Vibratory stimulation was always delivered to the right arm. Thus, the point of subjective equity (PSE) was measured by varying weight for the left arm while maintaining the weight on the right side at the reference weight (300 g). The comparison was repeated ten times for each weight sample under each stimulation condition. In total, we conducted 270 trials. The order of the trials was pseudo-randomized.

Before starting the weight comparison, calibration of each vibration actuator and a practice session for lifting movement were conducted. The vibration amplitude was adjusted to 70 m/s^2 using accelerometers (Adafruit, LIS331HH). Following this calibration, we checked the participants' ability to perceive the kinesthetic illusion in the intended direction.

In the practice session, the participants were instructed to conduct lifting movement around the shoulder joint, ascending for two seconds and descending for two seconds at 10~15 deg/s. The angular velocity of both arms was monitored using gyro sensors (BMX055) attached to the forearms, and the values were displayed on a front screen. Sound cues were delivered through headphones at the start, reversal, and end of each movement. White noise to mask vibration noise was also served during the movement. The participants practiced the movement, guided by the sound cues and velocity feedback, until they became accustomed to the motion.

We conducted the experiment with two participants (aged 22-24, one right-handed and one left-handed) recruited from our laboratory to grasp a tendency of the results and to assess the effectiveness of our approach.

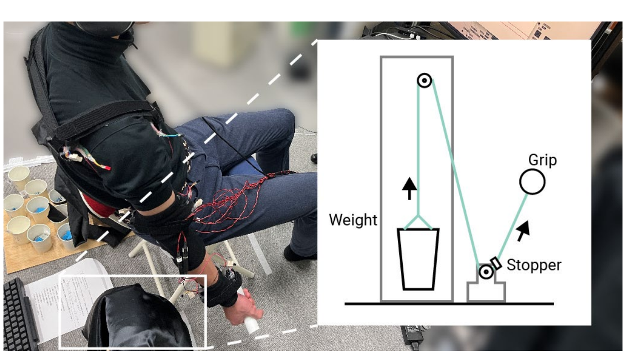

Figure 2: The structure of the pulley equipment.

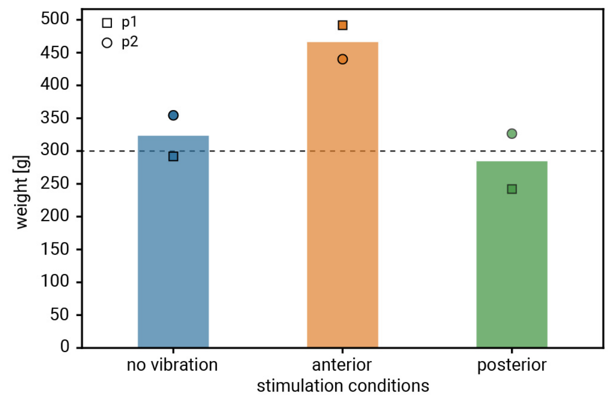

Figure 3: Results of two participants on each stimulation condition.

III. Results and Discussion

The results from the two participants are shown in Figure 3. The PSE under each condition was calculated by fitting a normal cumulative distribution to the proportion of responses of each participant. Under anterior stimulation, both participants perceived a significantly increased sense of heaviness. With posterior stimulation, although the difference from the reference weight is smaller than the anterior condition, the results are less than the no-vibration condition within each participant.

A participant (p2) noted that the effect of tendon vibration could vary within a single lifting movement. For instance, although they felt "lighter" with posterior stimulation during the ascent, the perception changed to "heavier" during the descent. This variation sometimes led to confusion in answering the heaviness. This implies that the mechanism might not be simply due to the kinesthetic illusion.

In conclusion, the results suggest that tendon vibration may potentially decrease the sense of heaviness. We plan to expand our participant pool to gain a deeper understanding of the underlying mechanisms.

References

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