Grip Force Modulation by Finger Posture

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ABSTRACT

Modulation of grip force has several applications such as sports. We speculated that as mupltiple fingers mechanically interact with each other, it might be possible to adjust grip strength by controlling the movement of single finger. We also speculated that changing grip strength may affect the weight perception of an object on grasping. In this paper, we investigated whether grip strength could be modulated by a specific finger posture, and found that it can be reduced by stretching some fingers, specifically middle finger and ring finger. Preliminary result of weight perception modulation is also reported.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *HCI theory, concepts and models.*

KEYWORDS

Finger posture, Grip force, Virtual reality, Weight perception

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1 INTRODUCTION

Many types of object manipulation require gripping. If grip force can be externally controlled, sports and force presentation in VR are expected applications.

In sports like baseball, tennis, badminton, and many others that require the use of hand-held equipment, it is often not only necessary to simply grasp strongly, but also to apply appropriate grip strength at specific times. Thus, external adjustments of grip strength might be applicable to sports education.

Alternatively, external control of grip strength might be applicable to the presentation of weight in VR space. Various factors such as skin deformation and proprioceptive sensation are involved in weight perception [9][8]. If grip strength is weakened via external control in a VR setting, the user might feel that an object is more difficult to grasp, and this may affect the weight perception of the object, such as a controller, that the user is grasping. Generally, the presentation of weight and force in VR space requires a large presentation device [11][14][2]. Control of grasp force might enable the use of more compact, lightweight, and potentially wearable force feedback devices.

It is known that grip force is affected by body or finger posture. Richards et al [10] discussed the relationship between forearm posture and grip strength, and Kuzala et al [3] studied the relationship between arm posture and grip strength. However, these studies were restricted to the posture of the arm and forearms. Multiple fingers are known to interact with each other while exerting grip force, and Ohtsuki et al [15] reported that the finger that most affects grip force in humans is the middle finger, Olatsdottir et al [5] and Danion et al [4] also studied finger interactions, and Duinen et al [6] studied the functions of individual fingers on grip force. However, no previous studies have conducted a detailed examination of finger posture and grip strength. Based on the above observations, we decided to seek possibility of modulating grip force by controlling the posture of one finger.

This paper is an initial step of grip force modulation by finger posture control, and we report the effect of individual finger posture on grip force, as well as subjective comfort. We also report the preliminary observation of the influence of of finger conditions on weight perception.

2 EXPERIMENT 1: THE EFFECT OF SINGLE FINGER POSTURE ON EXERTED FORCE

2.1 Experimental overview

In this experiment, we examined the relationship between finger posture and grip strength. Since all of the fingers are connected via tendons, extension of one finger hinders bending of the other fingers. This might cause weakening of grip force. We examined the relationship between finger posture and grip strength, as well as the feeling of comfort when grasping, by changing the finger posture and measuring the grip strength. Ohtsuki et al [15]. reported that the middle finger most affects grip strength. Thus, we changed the posture of the middle finger, as well as the neighboring index finger and ring finger, and validated the relationship between finger posture and grip force.

2.2 Experimental device

We measured grip force using a digital grip force meter (B01J 569 PLY, NFORCE). We also prepared triangular acrylic plates (thickness 15 mm) cut into pieces at 10 Âř, 25 Âř, and 40 Âř, to facilitate the immobilization of individual fingers at these angles.

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2.3 Experimental conditions

We recruited ten right-handed participants (nine men and one woman) who were 21 to 23 years old. We conducted grip strength measurements with their dominant hands. The participants could not see the value on the grip strength meter during the experiment, and the experimenter recorded the numerical values. There were three fixed finger angles (10 Âř, 25 Âř, 40 Âř) and three different restrained fingers (index finger, middle finger, ring finger) for a total of nine conditions, presented in random order.

2.4 Experimental procedure

The experimental procedure was as follows. (1) We measured the grip strength of the participant using a grip strength meter. There was no fixture device. (2) We measured the grip force with one fixture device set to one finger, as shown in Figure 1. (3) Participants rated the âĂIJcomfortâĂİ of the grip force using a seven-step Likert scale (1: comfortable, 7: uncomfortable). (1) through (3) were performed in random order for the nine conditions. Each measurement time was about 5 seconds (sufficiently short to limit muscle fatigue [13]), and there was a two-minute break between each trial to enable recovery [12].

Figure 1: Apparatus for Experiment 1

2.5 Experimental result

Grip strength for each condition is shown in Figure 2, and grip comfort is shown in Figure 3. The average grip strength for each fixture position was always maximum for fixation of the index finger, followed by the middle finger and then by the ring finger. This pattern was also observed for the feeling of comfort for each fixture position. For the grip strength value measured via a grip strength meter, we conducted a two-factor analysis of variance for each finger and for each angle. The interaction of angle condition ÃŮ finger condition was not significant (F (4, 81) = 0.068, n.s.).
As we did not find an interaction, we averaged and compared the results for each finger and each angle. Figure 4 show the results of multiple tests conducted using the Tukey method. Figure 5 shows the results of multiple tests conducted using the Kruskal-Wallis method for each finger and each angle. Statistically significant pairs are shown in the figures.

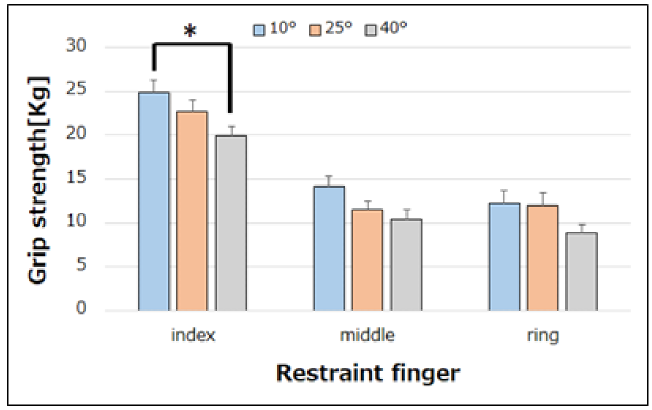

Figure 2: Grip strength (*p < 0.05,p < 0.01,***p < 0.001)**

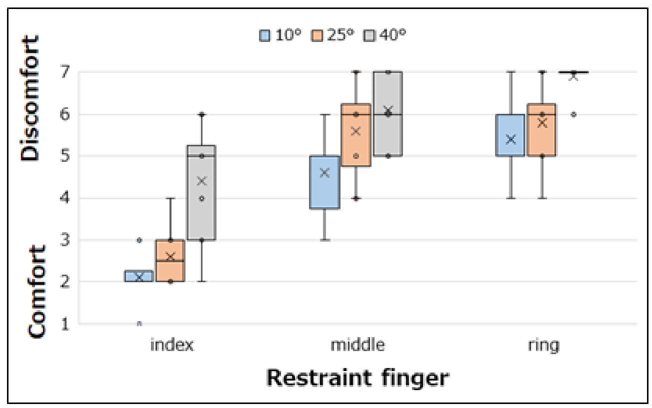

Figure 3: Grip comfort (*p < 0.05,p < 0.01,***p < 0.001)**

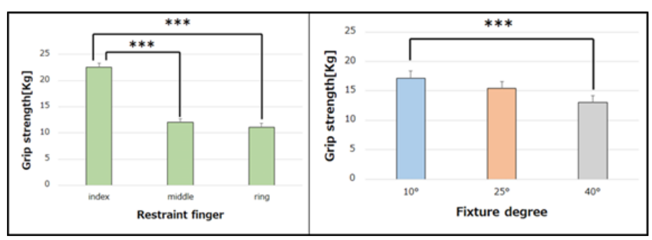

Figure 4: Grip strength averaged for each finger(left) and each fixture(right) (*p < 0.05, **p < 0.01, ***p < 0.001)

2.6 Discussion

Although grip discomfort was small for the index finger, this finger does not appear to be suitable for the purpose of this study because the decrease in grip strength was small compared with that observed for the middle and ring fingers. We found no large

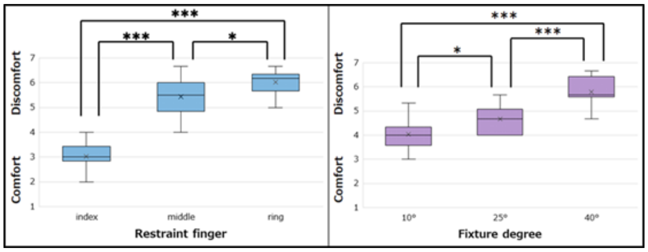

Figure 5: Grip comfort averaged for each finger(left) and each fixture(right) ($^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$)

differences in terms of grip strength between the middle finger and ring finger. Considering the angle, we found a significant difference in grip strength between 10 Âř and 40 Âř. The grip strength was significantly reduced by bending the middle finger or ring finger to about 40 Âř towards the back side of the hand. In addition, we found a significant difference between the feeling of comfort in the index finger, middle finger, and ring finger, such that the ring finger appears to be a good choice for achieving grip force reduction without discomfort. Also, there were significant differences between all fixture pairs, indicating that we might be able to modulate the grip force in an analog manner.

3 EXPERIMENT 2

3.1 Experimental overview

In this experiment, we investigated whether the decrease in grip strength confirmed in the previous experiment affected the weight perception of the gripped object. As mentioned in section 1, if modulation of grip force affects weight perception, this phenomenon may be useful for presenting different weights in VR space.

3.2 Experimental device

Given the results of the previous experiment, we prepared a finger fixation device that raised the ring finger by 40 Âř from the other fingers. We prepared bottles with several different weights by changing the mass of water such that the total weight ranged from 515 g to 550 g in 5 g steps.

3.3 Experimental conditions

We recruited eight participants, seven men and one woman (21 to 23 years old, all right-handed). They were asked to sit on a chair and lift weights using their dominant hands. The weight was positioned on a table at the same height as their elbows. We asked them to hold the weight with all of their fingers positioned close together except for their thumb, and to hold it with their finger pads as shown in Figure 6. The lift began from a position in which the little finger touched the table.
There were three experimental conditions. In the first, the participants used a normal gripping posture (normal finger posture condition). In the second, they were asked not to touch their ring finger to the bottle (four-fingers condition). In the third, their ring finger was bent at 40 Âř using the fixture device (four-fingers fixed condition). In all conditions, the fixture was attached to the hand so that the weight of the hand did not change among conditions. Participants closed their eyes during the experiment.

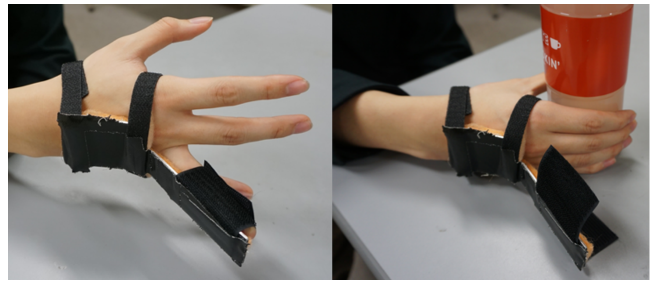

Figure 6: Apparatus for Experiment 2

3.4 Experimental procedure

The experimental procedure was as follows.
(1) Select one finger posture condition from the three, and attach the device to the hand. (2) Lift a weight of 530 g with the finger posture selected in (1). (3) Change to a normal finger posture, randomly select one weight among the eight options, and ask the participant to report which is heavier between (2) and (3). (4) Repeat (2) and (3) so that each weight is repeated ten times in a random order. Procedures (1) to (4) were conducted for all three finger postures. The order of the finger posture conditions was balanced among participants.
We compared the standard weight (530 g) in each finger posture condition to that of the comparison weights (515 g to 550 g) in the normal condition.

3.5 Experimental result

The results are shown in Figure 7 (normal finger posture), Figure 8 (four-finger posture), and Figure 9 (four-finger fixed posture). The horizontal axis shows the eight weights for the normal finger posture and the vertical axis shows the ratio of trials in which the normal finger posture was perceived as heavier. Fitting was carried out using a cumulative Gaussian curve to obtain subjectively equivalent points and a 75% discrimination threshold.
Since the participant group in this experiment was small, we did not carry out statistical tests, but instead focused on tendencies. The subjective equivalence point was smallest (523 g) in the normal finger posture condition, and the values in the other two conditions were very similar (527 g). The 75% threshold value in the normal finger condition was 11 g, that in the four-finger condition was 18 g, and that in the four-finger fixed condition was 20 g. This indicates that the threshold in the normal condition tended to be smaller than that in the other two conditions.

3.6 Discussion

Our data implied that lifting a finger during gripping might slightly change the perception of the weight of the object being grasped. However, we did not find a difference between the four-finger condition and the four-finger fixed condition. One possible interpretation is that the weight perception was modulated by change of total contact area of the fingertips, by changing from five fingers to four

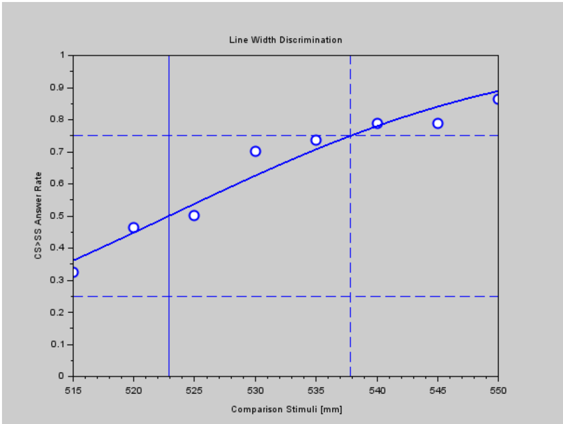

Figure 7: Results for the normal finger posture condition

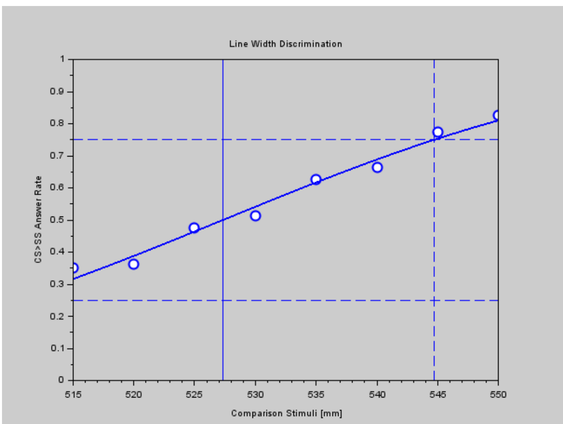

Figure 8: Results for the four-finger posture condition

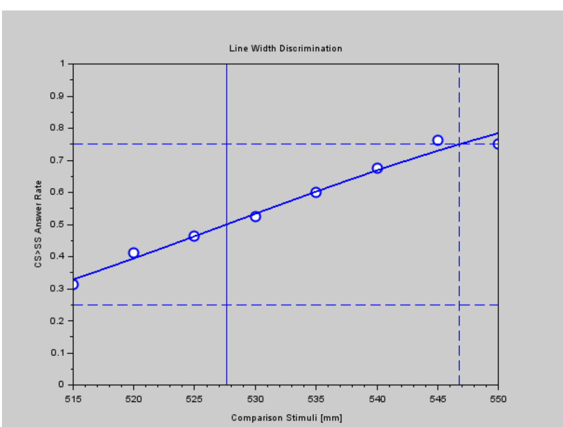

Figure 9: Results for the four-finger fixed posture condition

fingers, since it was known that skin sensation modulate weight perception [1]. The change in the number of fingers may also be related to the ambiguity (the 75% threshold value has become larger), possibly due to mechanical instability. There were also possibilities that different phenomena were associated with four-fingers fixed condition and four-fingers condition, but caused similar threshold value as a result. The former might be caused by changing the "posture" of the finger and the decrease in the grip strength, as we have expected, while the latter may be caused by the muscle activity. Muscle activity, or the sense of effort is known to affect weight perception [7], and in our case, having to lift the ring finger by himself/herself might cause additional muscle activity, which affected the weight perception.
As this experiment was preliminary, we cannot conclude the cause, nor if the finger conditions really affected the weight perception, and further investigation is necessary.

4 CONCLUSION

We examined a method for externally modulating user grip strength by changing the posture of the finger. This method may be useful in sports training and for presenting weight in VR space.
In Experiment 1, we found that the posture of the middle finger and ring finger strongly affected the grip force. In terms of comfort, the ring finger appears to be a good option for such manipulations. In Experiment 2, we preliminary examined the relationship between weight perception and finger posture, and found that the four-finger condition and four-finger with fixture condition might have elicited the perception of heavier weight and ambiguous weight. Our future work will include more detailed measurements, investigations of the cause of the decrease in grip strength and weight perception, and utilization of this phenomenon in practical applications such as sports training and the presentation of different weights in VR space.

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