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EMG Activitiy of Force Sensation Evoked by Vibration Stimulation

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***Abstract*:** Force display devices used under virtual environments are desired to be small and simple not to restrict users' movements and comforts. Force sensations of fingers are evoked when vibro-tactile stimulation is applied onto the fingertips. This phenomenon is expected to be used for a simple and small force display, since the users wear only tiny vibrators on their fingertips. The aim of this study is to clarify the relationship between the force sensations by vibro-tactile stimulation and the activities of electromyogram (EMG) of fingers. As a result, it is shown that EMGs of extensor indicis and extensor digitorum are more active than those of other finger muscles, and that the force sensations of index fingers in extendor direction are perceived. The vibration stimulates extensor muscles more effectively.

Keywords: force sensation, vibration, fingertip, EMG, muscle spindle.

I. INTRODUCTION

Force displays and feedbacks are needed in order to handle objects effectively under virtual environments. A number of force display devices have been developed with various methods. Some of them have been available commercially. Most of these devices employ desk /floor grounded or exoskeleton structures using arms or wires for force transmission. As the display areas are expanded, the whole sizes of force display devices have to be enlarged. However, large displays restrict portability and convenience. From this view point, force display devices are desired small and simple. If the mechanisms and configurations of force displays became small and simple, a number of new applications, such as a hand-held electronic game device, could be developed. Some studies have been conducted to develop small and simple force displays. For examples, electrical stimulation directly to muscles has been studied to elicit force sensation [1], and a hand-held force device using angular momentum change with flywheels has been proposed [2].

We have been studying force sensations of a fingertip evoked by vibro-tactile stimulation [3]. Figure 1 show that force sensation of a finger is evoked in the direction of extending, when vibro-tactile stimulation is applied onto the fingertip. The forces are felt with only a tiny vibrator, and the finger feels resistance (anti-force) in the direction of extending. This phenomenon is expected to be used for a new force display. In our

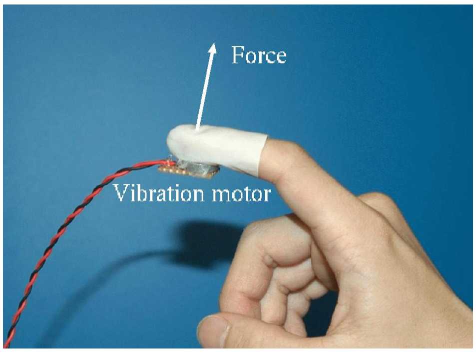

Fig.1. Experimental system

previous studies, the force sensations were psychophysically investigated with a vibration motor stimulating a fingertip. The strengths of the force sensations were measured as vibration intensities were changed. In addition, the sensitivities of force sensations are affected by arm and finger postures and with each finger were examined. It was found that forces can be perceived with vibration over thresholds of vibration intensity, that the sensitivities are affected by the arm and finger postures, and that the sensitivities are different among five fingers.

Although the force sensations were psychophysically measured, the activities of muscles were still unknown. When the forces are felt, finger muscles are expect to work by vibration stimulation. In this study, when force sensations of fingers are evoked by vibro-tactile stimulation onto fingertips, the activities of the

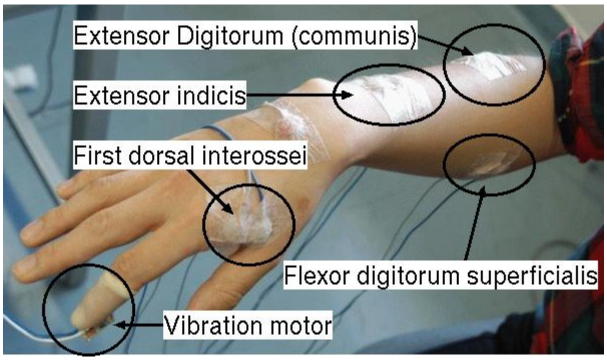

Fig.2. Electrodes to measure EMG.

finger muscles were examined by electromyogram (EMG).

II. MEASUREMENTS

From our previous studies, when a tip part beyond distal interphalangeal (DIP) joint of a finger is stimulated, force sensation is felt. In addition, the sensitivity of force sensation of forefinger is higher than those of other fingers. Therefore, the fingertip of palm side of forefinger was stimulated in these experiments. A simple device including a fingerstall and a pancake-type vibration motor was used for the stimulation. Figure 1 shows this device. The vibration motor used in this study includes a DC coreless motor and an eccentric weight, which are used in cellular phones commercially. This simple structure allows user's free postures and movements, and stable contact between the skin of the fingertip and the vibration motor. The stimulation intensities were measured in terms of acceleration with a piezo-accelerometer attached to the motor. The stimulation intensities on the skin surface are a little different from those of the motor. As applied voltage to the motor increases, the stimulation intensity increases almost linearly, and the vibration frequency changes from 50 to 100[Hz].

Since the stimulation part was fingertip of forefinger in this study, surface electrodes to measure EMGs were placed on muscles moving the forefinger. Figure.2 shows the setup points of these electrodes. These muscles were "extensor digitorum (communis)", "flexor digitorum superficialis", "extensor indicis", and "first dorsal interossei". The EMGs were measured with DEGITEX LAB Co., Ltd., Polymate II AP216. Seven healthy adult subjects were used. They were male and 21-25 years old.

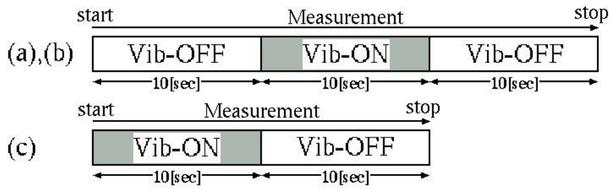

Fig.3. Experimental protocol

The EMGs were rectified and integrated every 0.1 s. In the psychophysical experiments in our previous study, the sensitivity of the force sensation is higher when the whole arm floats in the air. (Afterward this posture assume basic posture) In the experiments mentioned here, a subject wore the vibration device with the basic posture, and EMGs were measured when the subject posed and moved the finger with the following three posture and movement patterns: (a) flexion, (b) extension, (c) movement and vibration was on and off. Figure3 shows the measurement protocol.

(a) Vibration stimulation in finger flexion state was given every 10s. The duration of EMG measurement was 30 s (Vibration OFF / ON / OFF)

(b) Vibration stimulation in finger extension state was given every 10s. The duration of EMG measurement was 30 s (Vibration OFF / ON / OFF)

(c) A finger was moved voluntarily. The index finger was flexed and extended slowly for 10s. The subject repeated these movements twice for 20s. Vibration stimulation continued for 10s from the beginning. The EMG was measured for 20 s.

The rates of change were calculated with comparing the EMG of the vibration ON state with that of OFF state by the following methods: At first, EMGs were averaged every 10 s of each section. Next, the decline rates before and after vibration OFF and ON in (a) and (b) were calculated respectively. A rate of change was assumed the average of rate of decline before and after. In (c), a rate of change assumed a rate of decline of OFF after ON. A rate of decline shows in the following equation:

$$\text{A rate of decline} = (\text{Vib OFF}/\text{Vib ON}) \times 100$$

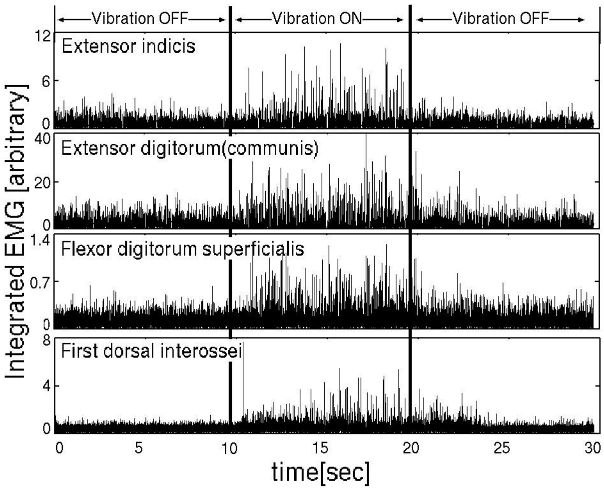

Fig.4. The EMG of the finger in the flexion state

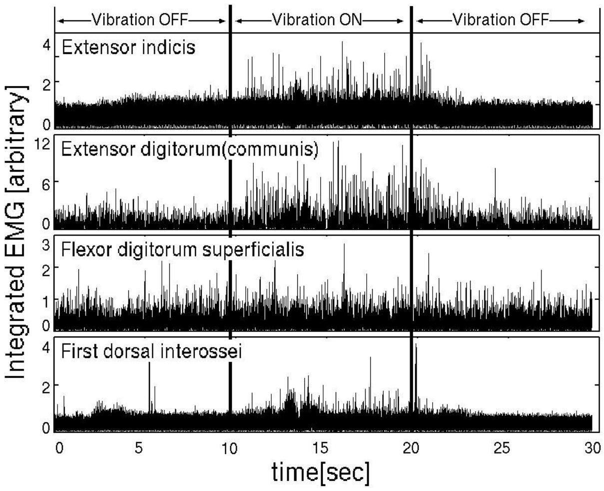

Fig.5. The EMG of the finger in the extension state

III. RESULTS

1. The EMG of the finger in the flexion state

Figure 4 shows an example of the EMG activities of Figure 4 shows an example of the EMG activities of the finger in the flexion state. The EMG activities of "extensor digitorum (communis)" and "extensor indicis" increase clearly during vibration. Table 1 shows the average change rates of all the subjects. The average values of "extensor digitorum (communis)" and "extensor indicis" are larger, and those values of "first dorsal interossei" are smaller.

2. The EMG of the finger in the extension state

Figure 5 shows an example of the EMG activities of the finger in the extension state. The EMG activities of "extensor digitorum (communis)" and "extensor indicis" increase clearly during vibration in the same mannor as those in Figure 4. In addition, the EMG activities of "flexor digitorum suerficialis" and "first

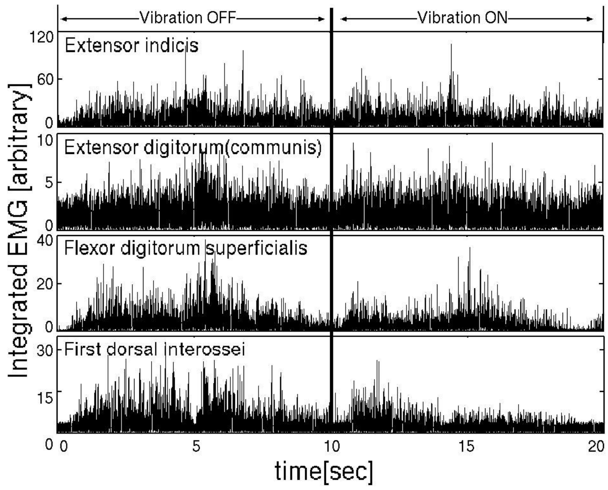

Fig.6. The EMG in the movement condition

Table 1. Average and SD of a rate of change

muscle	Flexion (SD)[%]	Extension(SD)[%]	Movement(SD)[%]
Extensor indicis	83.3(7.5)	82.9 (15.2)	83.0 (13.0)
Extensor digitorum (communis)	81.3(13.9)	85.5 (11.1)	81.9 (14.1)
Flexor digitorum superficialis	98.6(3.1)	95.1 (9.5)	88.4 (14.1)
First dorsal interossei	94.7(4.9)	86.8 (18.3)	88.2 (8.0)

dorsal interossei" increase a little, too. Table 1 shows, the EMG activities of "extensor digitorum (communis)" and "extensor indicis" are larger than those of "first dorsa interossei", similarly as shown in Result 1.

3. EMG of the finger in the movement condition

Figure 6 shows an example of the EMG activities with slow finger movements. The figure shows a change of EMG activities by the vibration stimulation cannot be observed during finger movements. Table 1 shows that the average of the change rates of extensor digitorum (communis) and extensor indicis are large. Those of flexor digitorum superficialis and first dorsal interossei" are also larger, but not so large as those of extensor digitorum (communis) and extensor indicis. The EMG activities are higher during the finger movement in the experimental condition(c) than those in the stationary conditions, (a) and (b).

From these results, vibration stimulation to a fingertip affects extensor muscles more effectively than flexor muscles. After confirming the normal distribution and the dispersion of the data, the two factor analyses of variance was performed in terms of the rate of change (Flexion - Extension - Movement state × Each EMG). The main effect of the rate of change is accepted ($F_{3,21}$ =

5.68, $p < 0.05$). In addition, multiple comparison tests (Scheffe's procedure) were performed. As a result, "extensor indicis" versus "flexor digitorum suerficialis" and "extensor digitorum (communis)" versus "flexor digitorum suerficialis" are accepted in four kinds of EMG ($p < 0.05$).

From these results, the EMGs with vibration stimulation to a fingertip are more active than those without vibration. In addition, it is supposed that the vibration stimulation affects extensor muscles more effectively. Consequently, it is considered that the force sensation felt in flexion direction is produced with some physiological mechanisms.

IV. CONCLUSION

It has already been known that a muscle contraction and an illusion of a joint angle are caused with a muscle spindle excited by vibration given onto the skin surface [4][5]. From our experiments, it is guessed that muscle spindles are stimulated by vibration propagating through a finger extensor tendon from a fingertip, and that force sensation is induced with extensor muscle contraction. When the fingers flex, the extensor contract, and it causes resistance (anti-force) in the direction of extending. It is conjectured that efforts against extensor muscle contraction to maintain the joint angle of a finger produce the force sensation.

V. SUMMARY

In this study, when force sensations of fingers are evoked by vibro-tactile stimulation onto fingertips, the activities of the finger muscles were examined by EMG. The results indicate that the EMG activities are observed with force sensation evoked vibration stimulation, and that some physiological mechanisms are expected. If this phenomenon is used, a new and simple force display device will be developed.

However, the users feel not only forces but also vibration. If a user grasps a vibrating virtual object, it will be acceptable. But, the vibration can be a disadvantage as an interface device for general applications.

To develop practical force display devices and applications, further studies shall be conducted to elucidate the perceptual properties of the force sensation and to develop potential applications.

VI. ACKNOWLEDGEMENT

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