Research of Conditions of stimulus for Inducing Grasping Force Control Reflex

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***Abstract*— Humans can change their grasping force before the grasped object unconsciously slips off their fingers. This reflex is called the grasping force control reflex. This paper describes the methods used to induce reflective grasping force control and presents the observed results. To clarify the stimulus conditions needed to induce reflective grasping force control, we developed an observation device with piezoelectric actuators and a force sensor. Vibration stimuli and force senses were presented to a human finger, and a change in the grasp force was observed by the force sensor. In this study, we changed the parameters of the vibration stimuli and force senses and detected the difference in the grasp force.**

I. INTRODUCTION

By obtaining optical and tactile information, humans change the grasping force and operate the target object naturally. Grasping force control occurs either by feedback control or by feed forward control. When optical information is available for predicting the object's weight, humans use feed forward control to change their grasping force. Otherwise, humans use tactile information obtained from the tactile disk in the finger surface and provide feedback control. This grasping force feedback control based on the tactile information obtained from the fingertip is executed unconsciously and is called the grasping force control reflex.

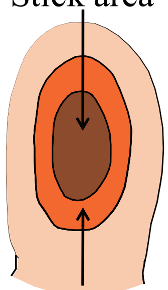

Fig. 1. Partial slip area and Stick area

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Previously Nakamoto and Konyo (2007) conducted a series of experiments to investigate the manner in which the grasping force control reflex should be induced. They presented a vibration stimulus to the finger as tactile information and simultaneously presented a force stimulus as the virtual object's weight. In Nakamoto and Konyo experience , it is suggested that presenting a vibration stimulus, which most do by firing the Meissner disk for 0.5 [s] in the partial slipping area shown in Fig 1, is most likely to induce the grasping force control reflex. Partial slipping is said to be perceived by tactile receptors such as the Meissner disk. In this case, a vibration stimulus, which fires the tactile receptors, represents partial slipping. However , the tactile conditions for inducing the grasping force control reflex are still unclear. Thus, it is suggested that a force stimulus perceived by muscle tissue and tendons could also affect the grasping force control reflex; however, it is not clarified.

In this study, our objective was to learn more about the conditions for inducing the grasping force control reflex by changing the parameters of the vibration stimuli and force senses. To determine the grasping force change, we developed an experimental device, which is capable of presenting various vibration stimuli and force senses and observing the grasping force. We conducted three experiments using this device.

In the first experiment, the objective was to determine which tactile disk was the most effective in inducing the grasping force control reflex. Partial slipping is said to be perceived by the Meissner disk; however, other tactile receptors can also be effective in inducing the grasping force control reflex. While the subjects were grasping the virtual object on the device, tactile receptors were stimulated selectively by vibration and changes in the grasping force were observed.

The second experiment was designed to investigate the

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effect of the vibration spatial pattern presented to the finger surface. The actual partial slipping area is shown in Fig 1, and in this experiment, the spatial pattern of slipping area differs from the actual slipping area spatial pattern. The objective of this experiment was to determine whether humans could recognize and use the spatial pattern of partial slipping area when inducing the grasping force control reflex.

In the third experiment, the effect of changing force senses was studied. In the previous research conducted by Nakamoto and Konyo , force senses were changed to represent a sudden change in the virtual object's weight; however, the effect of force sense was not investigated. Therefore, in this study, we presented a change in force sense, which represented a sudden weight change of the virtual object, as well as presented various vibration stimuli to the finger surface. Also comparing to the first experiment, it'll be clarified whether force senses sudden change is necessary in or not.

In the previous research, it was unclear as to whether a change in the grasping force was induced by muscle constriction. It was also unclear as to when the grasping force control reflex occurred. In this paper, while the subjects are grasping a virtual object with the device, the electromyograph observes muscle potential. With this muscle potential, we can determine the degree of muscle constriction and the timing of the grasping force control reflex. If the induced timing is within 50 [ms], grasping force control reflex can be clarified as myotatic reflex. Also if the induced timing is within 200 [ms], the reflex is brainstem reflex.

II. Method of inducing grasping force control reflex

A. Frequency and Amplitude

When grasping an object, humans perceive partial slipping with tactile receptors and respond with a grasping force control reflex. Tactile information is mainly obtained by tactile receptors such as the Merkel disk, Meissner disk, and Pacini disk. These tactile receptors have different frequency response characteristics to mechanical stimuli.

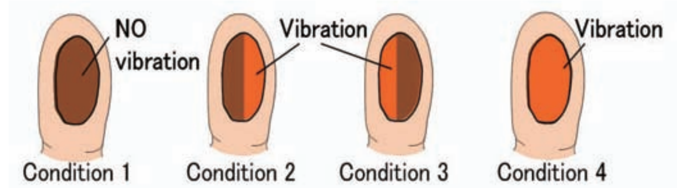

Fig. 3. Spatial pattern conditions

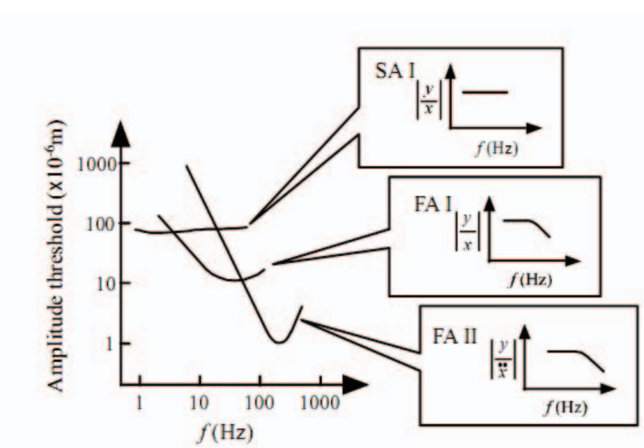

Fig. 2. Vibration perception threshold of tactile receptors

Fig 2 shows the vibration perception threshold of tactile receptors when presenting a vibration stimulus to the finger surface. According to this graph, the Merkel disk is most sensitive to vibrations at approximately 5 [Hz]; the Meissner disk is the most sensitive at about 30 [Hz]; and the Pacini disk is most sensitive at approximately 300 [Hz]. Considering this knowledge, tactile receptors can be selectively stimulated by presenting a vibration stimulus with the amplitude and frequency around the perception threshold of each tactile receptor. For example, the Pacini disk can be selectively induced by a vibration of 300 [Hz] and an amplitude of approximately 1 [μm].

In this paper, this method is called selective stimulation of tactile receptors. The perception threshold amplitude of each frequency is estimated individually prior to the experiment. Then, during the experiments, the subjects are presented the vibration amplitudes estimated in the preliminary tests. By varying the vibration frequency and amplitude and triggering each tactile receptor by the selective stimulation of tactile receptors, we investigated the relationship between the grasping force control reflex and the tactile receptors.

B. Spatial Patterns of Vibration

In grasping a real object, the partial slipping area and stick area of a human finger surface is as shown in Fig 1. The outer area is the partial slipping area, and the inner area is the stick area. Presenting vibration stimuli of 5, 30, and 300 [Hz] to the outer area represents an actual contact surface between a human finger surface and an object.

In this study, vibrations different from the actual spatial patterns were presented to the finger surface. These spatial patterns are shown in Fig 3.

C. Vibration presenting time

In previous works, Nakamoto and Konyo studied the grasping of a virtual object with different vibration presenting times to gain new knowledge about the effect of vibration presenting time on grasping force control reflex. The vibration presenting times were 0.1, 0.3, 0.5, 0.7, and 1.0 [s]. It was found that a 0.5 [s] vibration resulted in the best-induced grasping force control reflex. According to this finding, we set our vibration presenting time at 0.5 [s].

D. Force sense

In Nakamoto and Konyo's experiment, a force sense was presented to subjects to represent a virtual object's weight, and then, it was changed from 1 [N] to 3 [N] suddenly. This change in force represents a sudden change in the object's weight.

III. Grasping force control reflex observation device

An overview of the grasping force control reflex observation device is shown in Fig 4. The device is composed of three parts.

The first part is the structure to present vibration stimuli to the human's finger surface. The second part presents a force sense to the human's finger. The third part enables us to observe the grasping force control reflex.

The vibration stimulus structure is shown in Fig 6. The piezoelectric actuators are placed as vibrators, as shown in Fig 4. These vibrators are capable of firing every tactile receptor because they can present an amplitude of more than 80 μm and the response is more than 400 [Hz]. An attachment is placed on a piezoelectric actuator to present a vibration to the finger surface's inner area, as shown in Fig 1. A second attachment is placed on the other actuator to present a vibration to the outer area. The attachments used in this experiment are shown in Fig 5. The structure of attachments and actuators is shown in Fig 6.

The force sense presenting structure is composed of a Maxson DC Motor 118751, a wire (stainless diameter 0.5 [mm]), and a jig for contact to the finger. The force sense is presented by winding wire with the motor and hanging the device along the linear slider. The force sense is directly presented to the finger side with the jig, and the jig slides with the grasping device along the linear slider. By presenting a force sense to the finger side, the finger surface is free from tangential force and deformation. By presenting the force in this way, there is no displacement between the virtual grasping object and the finger surface; in other words, there is no real partial slipping. No subjects felt uncomfortable when the force sense was presented to the finger side.

The grasping force observing structure is composed of 3 axis force sensors (NITTA EFS-18M20A25-M10) and 1 electromyograph (NIHON KODEN multi-channel telemeter system) Fig 7. The force sensors measure the normal line grasping force change, and the electromyograph observes muscle constriction and the timing of the active muscle constriction. Electromyograph is attached on the skin surface shown in 8. The target muscles are used when bending fingers. Vibration presenting attachment is surrounded by finger support so that grasping force does not deforms piezoelectric actuator and attachments. Finger support also limits the contact area between attachments and finger surface to prevent individuals differences.

IV. Experiment for inducing the grasping force control reflex

A. Preliminary experiment

First, to estimate the perception threshold for vibration individually, subjects were presented with vibrations of different amplitudes. The frequencies used in this experiment were 5 [Hz], 30 [Hz], and 300[Hz]. A headphone with pink noise and an eye mask were placed on the subjects so they did not perceive any environmental changes. While the subjects were grasping the device, we changed the piezoelectric actuators' input voltage by 2 [V]. Each time subjects were asked if they perceived a vibration stimulus or not. The input was increased by 2 [V] from 0 [V], and the threshold amplitude was recorded.

Again, the input was decreased by 2 [V] from a well-defined input, and the threshold amplitude when the subject could not perceive a vibration stimulus was recorded. Then, using the method of limits, the perception threshold for vibration was calculated. This process was repeated 4 times in each frequency for a total of 12 times individually.

The results are shown in Table 1. The decline amplitude tendency was almost the same for every subject. This data does not contradict the information shown in Fig 2.

B. Experiment 1:Influence of Tactile receptors

In this experiment, subjects were presented with vibrations of various frequencies to investigate which tactile receptor affects the grasping force control reflex. The amplitude was set to the perception threshold individually for each frequency, as examined in the previous experiment. A headphone with pink noise and an eye mask were placed on the subjects so they would not perceive any environmental changes.

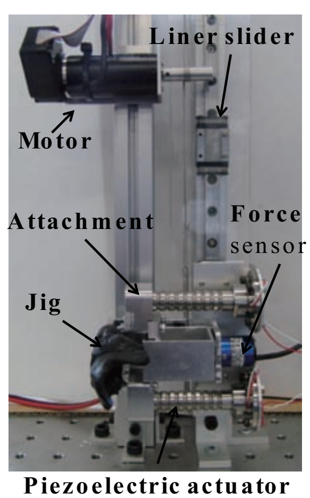

Fig. 4. Device overview

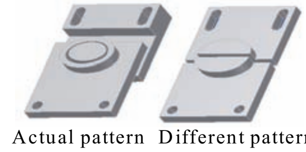

Fig. 5. Patterns of attachment

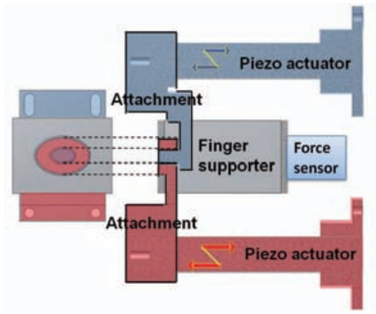

Fig. 6. Vibration Structure

Fig. 7. Figure of electromyography(NIHON KODEN)

1) Conditions: The subjects were 6 healthy males with ages ranging from 20 to 25 years. While the subjects had to keep grasping the device so it did not fall off, a force sense of 1 [N] was presented to the finger. Then, a vibration stimulus was presented suddenly at 7 [s] for 0.5 [s] since after 7 [s], the grasping force was almost stable.

The experiment to induce the grasping force control reflex with vibration was conducted under the 4 conditions below. The vibration stimulus was presented to the outer area shown in Fig 1.

Condition 1: Stimulate Pacini disk with 300 [Hz] vibration.

Condition 2: Stimulate Meissner disk with 30 [Hz] vibration.

Condition 3: Stimulate Merkel disk with 5 [Hz] vibration.

Condition 4: No stimulation presented.

Each condition was carried out 10 times randomly for a total of 40 times.

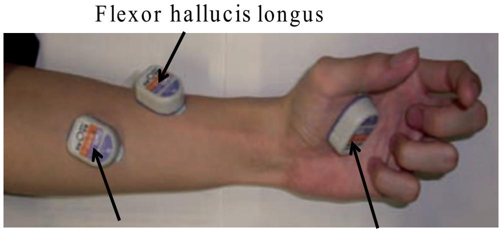

Fig. 8. Position of electromyography

TABLE I

PERCEPTION THRESHOLD AMPLITUDE

	5 Hz	30 Hz	300 Hz
Subject1 Amplitude [μm]	57.2	24.5	1.7
Subject2 Amplitude [μm]	54.2	23.7	1.9
Subject3 Amplitude [μm]	55.6	20.3	1.3
Subject4 Amplitude [μm]	48.5	22.1	1.6
Subject5 Amplitude [μm]	56.7	23.8	1.3
Subject6 Amplitude [μm]	51.7	19.1	1.1

2) Results: Fig 9 shows an example of the force sensor output. The output is normal to the direction of the grasping force. The grasping force change index is calculated by dividing the grasping force average of the previous 1.0 [s] vibration by the following 1.0 [s] vibration. A time of 1.0 [s] is sufficient to increase the grasping force and become stable.

An example of an increase rate is shown in Table 2. Values greater than 1.0 indicate the grasping force increased and the grasping force control reflex was induced.

Fig 11 shows the complete data for all the subjects. Under conditions 1 and 2, an increase in the grasping force was observed. As for the level of significance, condition 1's p value was 0.0013, and condition 2's p value was 0.0002. On an average, the number of times the grasping force was increased by the Meissner disk was larger than the number of times the grasping force was increased by the Pacini disk. Therefore, the Meissner disk was more effective in inducing the grasping force control reflex. And what is new in this experiment is we could induce grasping force control reflex without presenting force senses change. In the previous research, it is suggested that sudden force change is needed to induce grasping force control. However in this experiment grasping force increase was observed in spite of no force senses change were presented. This result shows tactile stimulus is used in grasping force control reflex especially tactile stimulus for Meissner disk.

C. Experiment 2:The affection of the spatial patterns of vibration

This experiment is conducted to investigate the affection of vibration spatial pattern presenting to finger surface. In this experiment, the spatial pattern of slipping area differs from the actual slipping area spatial pattern.

1) Conditions: While the subjects had to keep grasping the device so it did not fall off, a force sense of 1 [N] was presented to the finger. Then, a vibration stimulus was presented suddenly at 7 [s] for 0.5 [s] since after 7 [s], the grasping force was almost stable. Attachments are placed on the piezoelectric actuators and the vibration spatial patterns were changed like the patterns shown in Fig 3. Vibration used in this experiment is 30 [Hz] and amplitude is perceived threshold of preliminary experiment. 30 [Hz] vibration is the best induced grasping force control reflex in experiment 1. The subjects were 6 healthy males with ages ranging from 20 to 25 years. Each condition was carried out 10 times randomly for a total of 40 times.

2) Result: The result of grasping force increase rate is shown in Fig 12. The figure shows grasping force was increased in condition 1, 2, 3. In other words grasping force control reflex was induced when presenting vibration. But in this experiment there was no change among condition 1 and condition 2. This shows grasping force control dose not be affected by the vibration spatial pattern and it can be said only certain vibration is needed for inducing. Condition 3 also induced grasping force control reflex and the number of times grasping force increased was larger than condition 1 and 2. Maybe vibration area is also affected to grasping force control reflex, since spatial pattern condition 3 is double the area of condition 1 and 2. No significant changes of electromyography output were found in the experiment. This is because grasping force change is very little so the change of muscle potential could not be observed.

D. Experiment 3:Influence of force sense change

In this experiment, we not only presented a vibration stimulus to the subject's finger but also changed the force sense suddenly. In this case, force senses sudden change represents sudden change of the virtual object's weight. This is to estimate the affection of changing force senses to grasping force control reflex.

1) Conditions: The subject had to keep grasping the device so it did not fall off. The vibration was presented suddenly at 7 [s], as in Experiment 1, but the force sense was also changed suddenly from 1 [N] to 3 [N]. Force senses are presented to finger side by the jig. The conditions of vibration were the same as in Experiment 1. The subjects were 6 healthy males with ages ranging from 20 to 25 years. Each condition was carried out 10 times randomly for a total of 40 times.

2) Results: The result of increasing rate of grasping force is shown in Fig 13. In the level of significance 5%, all conditions are observed significant increase of grasping force after presenting vibration and force change. And no significant difference were found between the conditions. This means change of the force senses is greatly affected to induce grasping force control. Considering grasp force increase in condition 4 of no vibration, force stimuli change 1 [N] to 3 [N] is more effective than vibration stimulate in inducing grasping force control reflex. But in the previous experiment, no grasping force increase were found in vibration conditions of 5 [Hz], 300 [Hz] and no vibration with force change. And vibration of 30 [Hz] with force change could induce grasping force control reflex. Maybe force change is affected but in this experiment the stimulation was too big so vibration effect could not be observed.

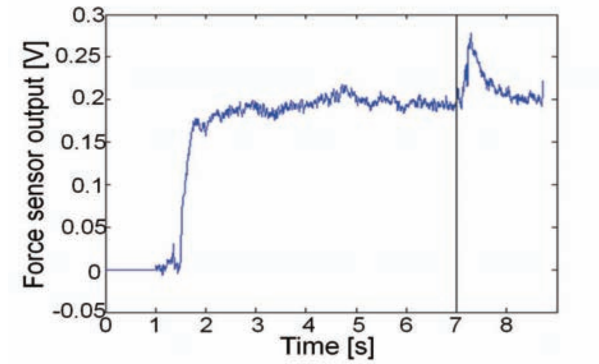

Fig. 9. Grasping force change

TABLE II

EXAMPLE OF GRASPING FORCE CHANGE RATE

	Frequency			
	300[Hz]	30[Hz]	5[Hz]	No Vibration
Grasping force increased rate	1.002804	1.006883	1.001746	0.972236
	0.992363	1.013298	0.995353	0.987061
	1.003767	1.019697	0.99314	0.980123
	1.026909	1.03659	0.964128	1.004414
	1.065278	1.047345	0.996095	0.990475
	0.992745	1.002277	1.010596	0.983972
	1.01466	1.012753	1.001145	0.994226
	1.000325	1.04642	1.006506	0.987625
	1.000191	1.010701	1.014315	0.951179
	1.000011	1.033348	1.013284	1.011038
Average	1.009905	1.022931	0.999631	0.986235
Number of increased rate	8	10	6	2

Fig 10 shows one example of the average of 10 trials electromyography output. After presenting vibration and force change at 7 [s], active muscle constriction was observed. This result shows grasping force increase was induced by muscle constriction. And the timing of grasping force control reflex is between 50 [ms] and 200 [ms].

V. Conclusion

In this study, to learn more about inducing the grasping force reflex, we observed the grasping force change when

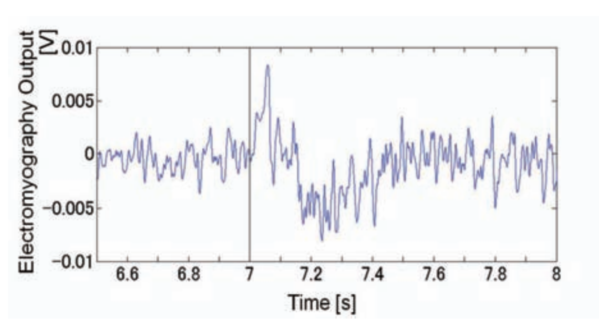

Fig. 10. Electromyography Output

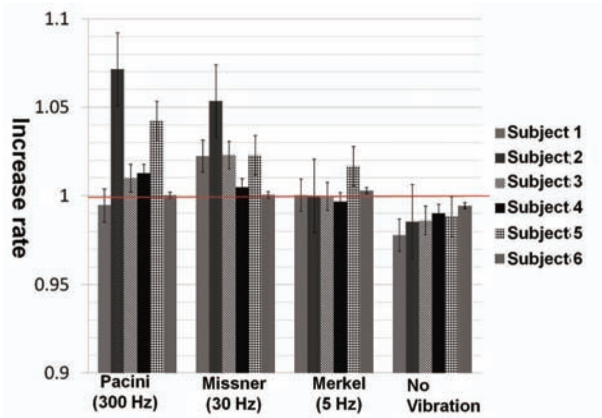

Fig. 11. Affection of tactile receptors

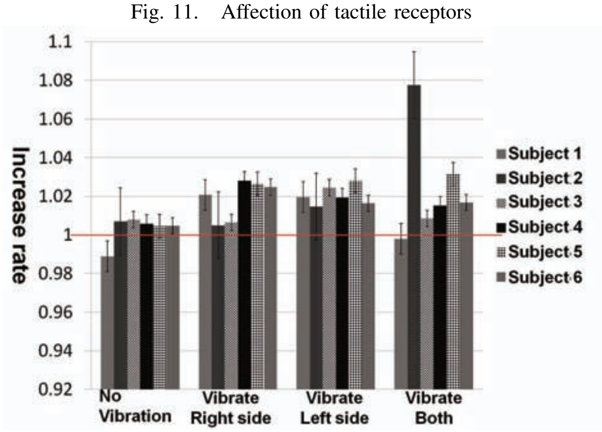

Fig. 12. Affection of spatial patterns

subjects were presented with different vibration parameters and force senses while grasping a virtual object.

First, we developed an experimental device that can present various vibrations and force senses simultaneously to represent the grasping of a virtual object. This device can also change the spatial pattern of vibrations presented to the finger surface. Using the observation system of the device, which includes an electromyograph, we can determine the grasping force change, muscle constriction, and the timing of active muscle constriction. With this experimental device, three experiments were conducted.

Experiment 1: The objective of this experiment was to determine which tactile disk was the most effective in inducing the grasping force control reflex. In this experiment, while subjects were grasping the virtual object with the device, tactile receptors were stimulated by vibration, and changes in the grasping force were observed. The results show that the grasping force control reflex occurs only when stimulated by the Meissner disk and the Pacini disk. In addition, the Meissner disk has a controlling effect on inducing the grasping force reflex.

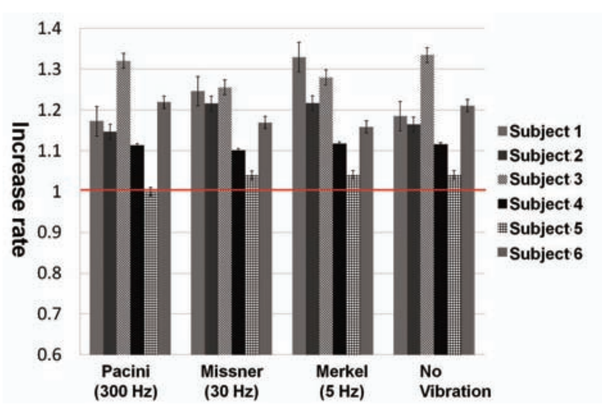

Fig. 13. Affection of force sense change

Experiment 2: The objective of this experiment was to investigate the effect of the vibration spatial pattern presented on the finger surface. In this experiment, the spatial pattern of slipping area differs from the actual slipping area pattern. The results show that the grasping force control reflex was induced when vibrations were presented; however, there were no changes between conditions 1 and 2. This shows that the grasping force control dose is not affected by the vibration spatial pattern and only certain vibrations are needed.

Experiment 3: The objective of this experiment was to determine the effect of changing the force senses. In addition to presenting a vibration stimulus to the finger surface, we presented a change in force sense that represents a sudden change in weight of the virtual object.Because of muscle potential activity, muscle constriction was observed and the timing was between 70 [ms] and 200 [ms] on average. According to this knowledge, grasping force control reflex supposed to be brain stem reflex.

The grasping force control reflex was induced under all conditions. Therefore, force sense has a greater effect on inducing the grasping force reflex than a vibration stimulus. In experiment 1 and experiment 2, grasping force control reflex were observed while no force sense change was presented. This result shows tactile stimulus can itself induce grasping force control reflex especially for tactile stimulus to fire Meissner disk.

VI. Acknowledgments

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