Original Article

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The property of muscle activity between finger skin and weight load with circular grip

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Abstract

This study measured the magnitude of electromyographic (EMG) activity and percent maximum voluntary contraction (%MVC) of the finger and hand muscles as the skin conditions (dry, rubber-glove, wet, soapy) and weights (500, 750, 1000g) of the object held varied. Sixteen normal young adult subjects who met the inclusion criteria were fitted with 4 pairs of surface electrodes on their flexor carpi radialis, extensor carpi ulnarlis, first dorsal interosseaus, and thenar muscles. Muscular activity was significant between low frictional (soapy) and high frictional conditions (dry, rubber-glove) ($p<0.05$). Muscular activity of the extrinsic muscle significantly increased with increasing weight load ($p<0.05$). Muscle activity of the intrinsic muscle often increased as the weight load increased. It was found that contraction between extrinsic muscles and intrinsic muscles was modulated during this grasping task.

Key words

Surface EMG, Extrinsic Muscles, Intrinsic Muscles, Skin conditions, Weight Loads

Ⅰ. Introduction

The hand grips object and manipulates tool, while adjusting the force of its grip, depending on the size and material of the object held[1]. Adjusting grip force means controlling that force in response to the nature of the material and weight of the object[2,3,4]. This adjustment process is continuous in daily life. The present study was undertaken to examine the act of gripping an object by analyzing the activity of the exogenous muscles of the fingers and hand as the surface skin condition and weight of the object held varied. The importance of skin friction in hand stability has been high lighted in studies observing grip force intensities.

Ⅱ. Subjects

The subjects were 16 female university students from 21 to 24 years of age (mean: 22.7 ± 0.9 years) who were right handed and had normal arm function. The right hand of each subject was tested. Hand dominance was determined by which hand the subjects used most in activities of daily living. The mean (SD) anthropometric measurements of forearm length, hand length, hand width, max hand width, grasp power, and three pad pinch power for participants are shown in Table 1. All of the subjects signed an informed consent form prior to participation in the study.

Ⅲ. Methods

1. Test conditions (Figure 1)

The subject was seated on a chair, with her right elbow resting on a table and her wrist joint held in an approximate 30-degree palmar flexion

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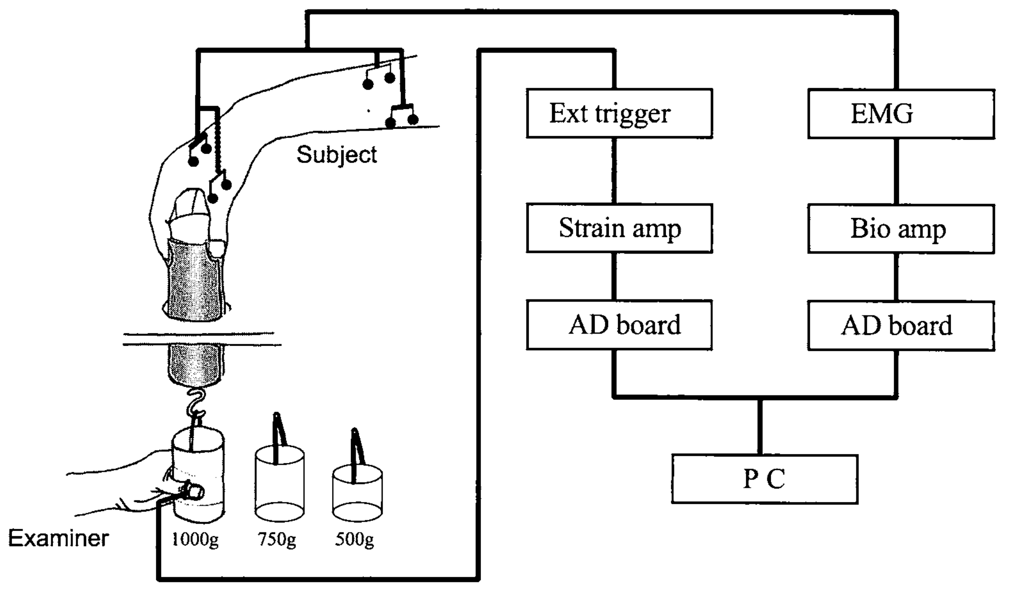

Figure1. Schematic drawing of the apparatus
The subject was seated in an upright position, with her right elbow resting on a table and the shoulder positioned in 30 degree flexion, the elbow at 80 degree flexion, the forearm in pronation, and the wrist in a neutral position. The subject gripped a cylinder with all five fingers in the posture (i.e., the palmar side of the fivefingers of her right hand).

position. In this position she gripped a cylinder with all 5 fingers, i.e., the palmar side of the five fingers of her right hand. The weight was masked so that the subject could not see it, to prevent the subject from adjusting her grip force on the basis of visual information. The room temperature was 21-24 ℃ and humidity was fairly low.

2. Electromyography

Electromyographic (EMG) activity was collected through the use of bi-polar surface electrodes spaced approximately 3 cm apart and located at the site of the muscle. The four muscles included two extrinsic muscles (FCR; flexor carpi radialis and ECU; extensor carpi ulnaris) and two intrinsic muscles (first DI; first dorsal interosseous muscle and TH; thenar muscle) are shown in Fig. 2. Surface electrodes were attached to the motor point of each muscle. Skin impedances were kept below 5KΩ. The raw EMG signals were pre-amplified, high-pass filtered at 30 Hz, and low-pass filtered at 1000 Hz. The processed signals were collected at 100 Hz, and fed through an A/D converter (Mac lab/ 8S) into a personal computer (Power Mac 8500/150; sampling frequency: 200 Hz) for analysis.

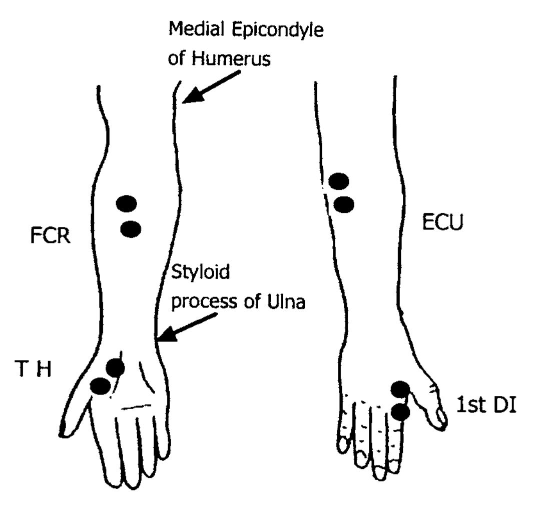

Figure2. Location of EMG electrodes on the finger flexor and extensor muscles (Basmajian J.V. et al. 1982)
For the flexor carpi radialis; the electrodes were centered around the 50 % point on a line from the lateral aspect of the biceps tendon at the elbow crease to the pisiform bone. For the extensor carpi ulnalis ; the electrodes were placed less than a finger's breadth from the posterior sharp border of the ulnar in the region 1/3 the distance between the olecranon process and the styloid prosess of the ulnar.
Thenar group muscle; the electrodes were placed vertical one finger's breadth inferior and medical to the abductors pollicis brevis site. First DI; the electrodes locations on the radial side of brachybaso of the index finger.

Table 1. Means (SD) for anthropometric data

Forearm length	:	24.2 (2.1) cm
Hand length	:	18.2 (0.9) cm
Hand width	:	7.8 (0.5) cm
Max hand width	:	19.8 (1.2) cm
Grasp power	:	26.6 (5.6) kg
Three pad pinch	:	3.4 (1.9) kg

3. Experimental design

The subject gripped various cylindrical objects made of vinyl chloride, 6 cm in diameter and 20 cm in height. The subject successively gripped the cylinders under four friction conditions: dry, rubber-glove, wet, and soapy conditions. The maximum static coefficient of friction[5], as calculated theoretically, was 0.14 for the soapy, 0.17 for the wet, 0.53 for the dry and 1.09 for the rubber-glove conditions. A hook was attached to the lower end of each cylinder so that it could be loaded with weights (500, 750, or 1,000 g).

4. External trigger switch

The experimental apparatus is shown in Fig. 1. The trigger switch circuit used to initiate measurement was designed as follows. The examiner wore stainless steel rings on the thumb and index finger. The trigger switch was turned on when the examiner's thumb and finger were in contact with the weight. The trigger switch was turned off when the weight was passed from the examiner's hand to the subject's hand. Measurement began automatically as soon as the trigger switch was turned off. Measurements lasted for 3 seconds.

5. Procedure

The subject successively gripped cylinders under four finger skin conditions in the following order: dry, rubber-glove, wet, and soapy conditions. The test was conducted with four weights (500, 750 and 1,000 g, in that order). There was a 3-minute interval between each session to avoid the influence of muscular fatigue.

6. Analysis method

Electromyographic patterns were converted into absolute values to calculate the mean amplitude, which was expressed as the percent maximum voluntary contraction (%MVC), calculated using the following equation: %MVC = (muscular potential during action/muscular potential during maximum contraction)$\times$100

7. Statistical analysis

The mean and standard deviation of %MVC, under varying sets of conditions, were subjected to one-way analysis of variance (ANOVA). Repeated measures ANOVAs were completed for the results of three weight loads and surface of skin conditions. ANOVA and paired t-tests with Bonferroni were used for post-hoc testing. A significance level of $p < 0.05$ was considered statistically significant.

Ⅳ. Results

1. Relation between muscular activity and skin condition at 500g weights load (Table 2, Figure 3)

When four finger skin conditions were tested, the activity of the extrinsic muscles (FCR and ECU) was significantly greater than that of the intrinsic muscles (TH and the first DI) ($P<0.05$). The activity of the extrinsic muscles was significantly greater when gripping under soapy

Table 2. Statistical significance of outcome for the muscles and skin conditions by Bonfferoni-Dunn method after ANOVA (weight condition: 500g)

(n=16)

skin conditions	FCR	ECU	T H	1st DI
Dry × Rubber	0.99	0.62	0.93	0.92
Dry × Wet	0.94	0.34	0.99	0.99
Dry × Soapy	0.001*	<0.001*	0.09	0.41
Rubber × Wet	0.97	0.96	0.98	0.97
Rubber × Soapy	0.002*	0.001*	0.32	0.81
Wet × Soapy	0.008*	0.006*	0.15	0.54

*Indicates significance at $p<0.05$.
FCR : flexor carpi radialis m.
ECU : etensor carpi ulnalis m.
T H : thenar m.
1stDI : first dorsal interosseous m.

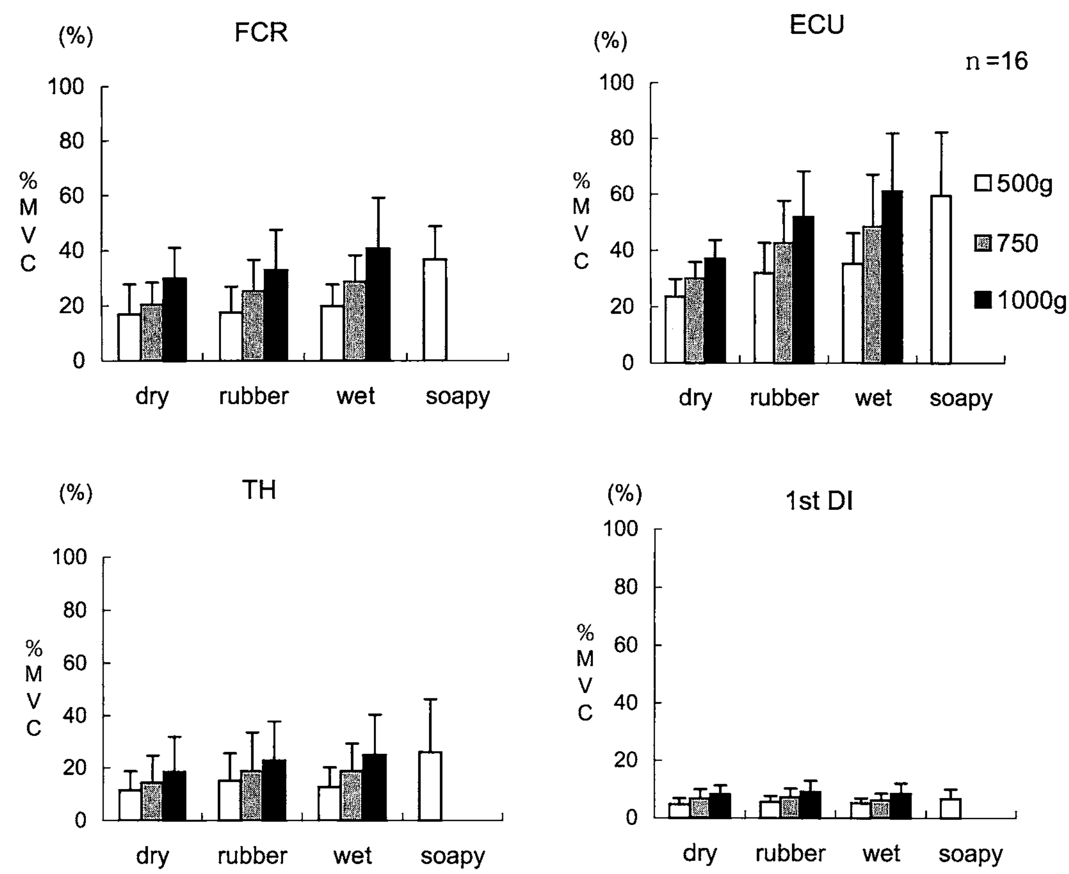

Figure3. Mean (SD) of muscle activities between weight loads and finger skin conditions
Mean and SD for the % MVC. An upper step is muscle activity of extrinsic muscle (FCR, ECU) with weight loads(500,750,1000g), under dry, rubber-glove, wet and soapy conditions. A bottom step is muscle activity of intrinsic muscle (TH, First DI) with weight loads (500,750, 1000g) under dry,rubber-glove, wet and soapy conditions.

conditions than under other skin conditions (P< 0.05). The activity of the intrinsic muscles was not significantly greater when gripping under soapy conditions than under other skin conditions. When muscular activities involving different skin conditions were compared, there were significant

Table 3. Statistical significance of outcome for the muscles and weight conditions by measure ANOVA (n=16)

weight conditions	FCR	ECU	T H	1st DI
Dry				
500g×750 g	0.73	0.08	0.84	0.33
500g×1000 g	0.03*	<0.001*	0.36	0.04*
750gr×1000g	0.13	0.06	0.69	0.57
Rubber				
500g×750 g	0.36	0.26	0.84	0.52
500g×1000 g	0.03*	0.01*	0.46	0.06
750gr×1000g	0.38	0.37	0.79	0.38
Wet				
500g×750 g	0.32	0.26	0.53	0.65
500g×1000 g	0.004*	0.01*	0.08	0.04*
750gr×1000g	0.13	0.29	0.51	0.23

*Indicates significance at p<0.05.
FCR : flexor carpi radialis m.
ECU : etensor carpi ulnalis m.
T H : thenar m.
1stDI : first dorsal interosseous m.

differences in muscular activity between gripping under dry and soapy conditions, or between soapy and rubber-glove conditions, wet conditions ($P < 0.05$).

2. Relations between muscular activity and weight loads (Table 3, Figure 3)

As the weight load increased, the activity of both extrinsic and intrinsic muscles increased. The muscular activity of extrinsic muscles showed significant gradual increases as the load increased to 500, 750 and to 1,000 g while gripping under any of the dry, wet, rubber conditions (500 × 1000g weight condition; $P < 0.05$). The activity of the intrinsic muscles often increased as the load increased, the first DI showing a significant increase under the 500 × 1000g weight condition.

Muscular activity relative to the load was also measured. The activity of the extrinsic muscles while gripping under dry, rubber-glove, and wet conditions increased in proportion to the load. Muscular activity increased as follows: soapy > wet > rubber-glove > dry conditions. The increase was significantly greater for the extrinsic muscles than for the intrinsic muscles ($P < 0.05$).

V. Discussion

The hand can continue gripping an object with minimal force, although the person can not see the object, based on the tactile information collected by the fingertips[3]. Westling and Johansson[7] reported that not only friction between the skin and the object but also the weight of the object greatly determines the grip force. In the present study, we examined differences in the characteristics of a person's grip with five fingers of cylindrical objects under different surface skin conditions and weights, by analyzing differenes in muscular activity. Muscle activity adapted with safety margins to the minimum ratio at which slipping would have occurred. This control system, which supports grasp stability, has been demonstrated previously for precision grip tasks[7-10].

1. Grip patterns and changes in muscular activity

The activity of the extrinsic muscles was significantly greater than that of the intrinsic muscles ($P < 0.05$). Gripping an object with 5 fingers is classification[11]. In this form of grip, the thumb is in opposition to the four fingers. Therefore, the four fingers flex at their DIP joints and grip the cylinder on their palmar faces. The musculus flexor carpi radialis of these four fingers serves as the major muscle determining grip efficiency. The musculus extensor carpi ulnalis, which showed the greatest activity among the four muscles, contributed greatly to increasing the grip force. This muscle may exert tenodesis-like action through dorsiflexion of the wrist joint, thus contributing to increasing the finger flexion strength.

2. Differences in muscular activity depending on the finger skin condition

The activity of all the muscles examined was high when the subjects were gripping cylinders with a low friction surface (slippery) under skin conditions such as wet and soapy conditions, while it was low when gripping cylinders with a high friction surface (less slippery) under skin conditions such as dry and rubber-glove conditions. However, the muscle activity under the dry condition was higher than the rubber-glove conditions; therefore, surface sensory input was interrupted, when the subject was wearing rubber glove. Then, excessive force was output in this situation. Mital's[21] suggestion that rubber-gloves would lead to a quicker onset of fatigue, and might lead to potential trauma disorders may not be logical. In other words, an object with a low coefficient of friction is perceived as likely to slip out of the hand and thus greater muscular activity is required to increase the grasping force retaining the object in the hand. Similarly, Nakamura, Sawada and Tsubota[12] reported that when minute adjustments are made to optimize pinching, small gaps between the fingertip and the object gripped are fed back as information. The results of the present study suggest that the grip force is affected not only by friction and the weight of the object but also by two other factors. One of these two factors is the relationship between sweat on the skin's surface and the surface material of the object gripped[14]. Adequate sweating is expected to improve the fit between a slippery object and the fingertips[15,16]. This idea was supported by the finding that the muscular activity needed to grip an object was smaller under smooth skin conditions (wet and soapy conditions) than under dry conditions, although both skin conditions had low coefficients of friction. The second factor is irregularities on the object's surface. Kinoshita[9] examined the relationship between weight and grip force using smooth materials (aluminum and plastic) and found that grip force increased linearly as weight increased. They also found that grip force decreased when the surface of the same materials were irregular. Their report suggests that if the irregular surface of an object comes in contact with the elastic palmar side of the fingers, the total skin surface contact area changes, leading to a change in grip force[7,17].

3. Changes in muscular activity associated with the weight load

The activity of the intrinsic muscles did not increase markedly as weight increased, while the activity of the extrinsic muscles showed a significant gradual increase as weight increased ($P < 0.05$). This suggests that the intrinsic muscles are less sensitive to the influence of weight loads, and work to keep the object within the grip.

It was also revealed that an increase in weight elevates vertical downward force ($F = mg\mu$, mg; weight loads, μ; coefficient of friction), which causes the object to slip out of the hand and that extrinsic muscles are required to generate grip force corresponding to the weight. In the present study, the activity of the extrinsic and intrinsic muscles while subjects gripped various objects was examined. Previous studies[18-19] measured the force used to grip a cylindrical object using a pressure sensor, and Ogawa and Nitsuta[20] measured the grip force using a strain gauge built into a cylindrical object. In the future, it is necessary to examine the adjustment of grip force in relationship to the skin conditions and weight of an object by analyzing the relationship between muscular activity and actual grip force.

Occupational therapists should incorporate several task conditions into hand evaluations and treatments during hand therapy. Additionally, occupational therapists possess skills for ergonomic-related activity analysis and activity modification.

Ⅵ. Conclusion

Differences in the force needed to grip a cylindrical object with 5 fingers under 4 different finger skin conditions and loaded at 3 weight levels were investigated by analyzing changes in muscular activity. The following results were obtained.

1. Muscular activity was high when the finger skin condition had low friction (soapy condition), while it was small when the finger skin condition had high friction. Muscular activity was low when the object's surface had high friction (dry and rubber-glove conditions).
2. The increase in muscular activity, following the increase of weight loads, was greater for soapy conditions than the other skin conditions, and it was greater with extrinsic muscles than with intrinsic muscles.
3. Grip force was related not only with friction and weight load but also with sweating on the skin surface and irregularities of the finger skin condition.
4. It is necessary to examine the relationship between grip force under different finger skin conditions and the muscular activity that generates this force.

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円柱把握における指尖部皮膚と重量負荷の違いによる筋活動特性

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要　旨

本研究は，把持する円柱の重量（500，750，1000 g）条件と，把持する手指皮膚（dry, wet, rubber-glove, soapy）条件下で，円柱を把持した時の上肢，手指の筋活動（%MVC）と筋活動量を測定した。対象は16名の若年健常者であり，表面筋電形で導出する被験筋は，橈側手根屈筋，尺側手根伸筋，第一背側骨間筋，拇指球筋の4筋であり被験側に電極を貼付した。筋活動は，摩擦係数の低い（soapy condition）は，摩擦係数の高い（dry, rubber-glove condition）に比べて有意に大きな活動を示した。外来筋の筋活動は手に把持する負荷重量が重くなるに従い有意に増大した。手内筋の筋活動は，負荷重量が著しく重くなった場合にのみ有意に増大した。把持課題における外来筋と手内筋の筋活動特性を明示できた。