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Generation of excess grip force after picking up a heavier object with the contralateral hand

Kazue Noda

In order to understand whether force corresponds to the weight of the object in respect to the contact surface pressure exerted by the thumb and index finger performed on one side influences the contact surface pressure exerted by the fingers of the other side, the grip forces of the right and left hands were measured under 3 conditions. Condition 1: Pick up a heavy object with the right hand, and then pick up a light object with the left hand. Condition 2: Pick up a light object with the right hand and then pick up a light object with the left hand. Condition 3: Pick up a heavy object with the right hand and then pick up a heavy object with the left hand. Subjects were 27 right-handed females (Age 22 ± 2.6 years). Grip force was measured as contact surface pressure exerted by the thumb and index finger. The peak value of the contact surface pressure of the fingers was recorded. The results showed that the contact surface pressure of a subject's grip force was high when the object was heavy and the contact surface pressure was low when the object was light, for both right and left hands. When the right hand picked up a heavy object and the left hand subsequently picked up a light object, excess power was generated. From this, it was understood that the force corresponding to the weight of the object in respect to information about the heaviness of a motion performed by one side, has an effect at the time of motion on the other side; and when a heavy object is lifted in the first motion, excess power will be produced in the second motion on the other side.

Key Words

Grip force,
Precision grip,
Weight,
contralateral hand

Introduction

In clinical occupational therapy, a movement known as a grip motion of peg and bead is used in many cases as training in situations where there is a problem with the grip or motion of a hand. Principally, this involves the training of disordered upper limbs where mo-

tion is performed on only one side of the upper body. However, the use of their sound side by patients undergoing rehabilitation can be thought of as a technique to facilitate the development of better capabilities for their other affected side. It has been postulated that if "the movement performed by one side influences the other side at the time of the movement", movement of the sound side immediately before movement of the affected side will help to generate greater power (Or be more suited to the activity), and thus can be considered as effective training for the palsied side (affected side).

It has been reported that in precision grip movements in humans, the weight of the object being lifted is one of the

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factors that determines the magnitude of the grip force applied.^{1,2,3)} Grip force is generated according to the weight, and the sensory impression of weight is memorized. During the following motion of picking up, the memorized sensory impression strongly influences the grip force generated for picking up by the fingers of the same side. However, this does not resolve the question of whether such memorized information regarding the weight has any influence on a movement event performed by the other side. To both elucidate and to answer this question, contact surface pressures of precision grips exerted by thumb and index fingers were measured in healthy female subjects.

Method

1. Subjects

Subjects were 27 healthy females, mean aged 22 ± 2.6 years (range 19 to 28), with no superficial/deep sensation deficits. All subjects were right handed when pitching a baseball, using scissors or chopsticks and when writing. Right-hand pinch force was 2.9 ± 0.8 kg (mean $\pm$ SD) and that of left-hand was 2.6 ± 0.6 kg.

2. Measurement units

Grip force at the time of movement was measured as a contact surface pressure. The grip object to be picked up could have its weight adjusted by removing weights from the bottom. For picking up, the upper part of the grip object was grasped with a palmar pinch between the thumb and index finger (Figure 1). To measure the contact surface pressure two air-packs (Air-pack type contact surface

pressure measuring system, AMI TECHNO) of $\phi 11$ mm $\times$ 17 mm were attached to the pulp of the individual thumb and the index finger. The weights placed in the grip object were of two types: a 301.0 g black film container (heavy film container) which contained a lead weight and was sealed, and a 7.5 g black film container (light film container) which contained nothing and was also sealed. These two different containers had identical appearances, and gave no visual cues in regard to the weight to the subjects. For measurements of contact surface pressure, an Air-pack type contact surface pressure measuring system AMI 3037-2 (AMI TECHNO) was used, and the contact surface pressure signal was converted from analog to digital using PowerLab 8 sp (AD Instruments). Data was stored using Chart v 4.1.2 (AD Instruments). The sampling frequency was 10 Hz.

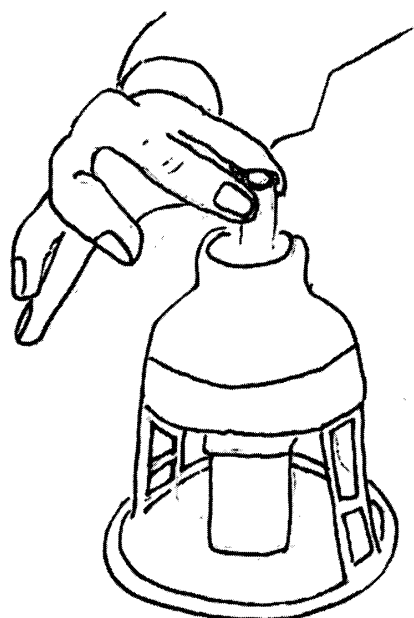


Figure 1. Gripping object to be picked up with a palmar pinch of the thumb and index finger.

3. Experimental procedures

The experiment was conducted as follows :

- 1) The subject sat down in front of a desk, and the height of the desk was adjusted to the same height as the position of the forearm when bending the cubital joint to 90 degrees. The chair was positioned to make a space of one fist-width (approximately 10 cm) between the desk and the subject's body. The grip object and the chair were arranged to a median frontal configuration.
- 2) Pinch force was measured as a palmar pinch of the thumb and the index finger. Measurement was conducted for the left and right hand, for a total of three times on each side, with the maximum measured value being designated as the pinch force.
- 3) The experimental procedure was explained verbally, and one practice run for each of the right and left sides was conducted with the light film container. We didn't warn the subject of the possibility that the weight of the grip object may change.
- 4) The subject was instructed to pick up the grip object with a palmar pinch of the thumb and the index finger and to hold it for approximately 10 seconds ; and then to put the object down in the place where it had originated. The subject was instructed to pick up the object with the necessary minimum force and not to use any fingers other than the thumb and index finger. To measure the movement under a more natural condition, instructions were not given during the course of the motion. Subjects were allowed to perform the motion of picking up at their own pace, and they could leave the object anywhere on the rest.
- 5) The first pick up motion was performed by the right hand, followed by the left. After the first set of measurements, in order to diminish the memory of the weight sensation, the subject was assigned a task not related to the experiment for 5 minutes. This consisted of a creative task ; making a 2-story house using toy blocks (Duplo). The experimental procedure progressed as ; experiment 1 (grip force), the non related task for 5 minutes (blocks), then experiment 2 (grip force), the non related task for 5 minutes (blocks), and finally experiment 3 (grip force) (Figure 2).
- 6) There were three types of conditions involving a light and a heavy object. Condition 1 : Pick up the heavy object with the right hand and then pick up the light object with the left hand. Condition 2 : Pick up the light object with the right hand and then pick up the light object with the left hand. Condition 3 : Pick up the heavy object with the right hand and then pick up the heavy object with the left hand. To decrease any influence from the sequence order, conditions 1, 2, and 3 were assigned at random.

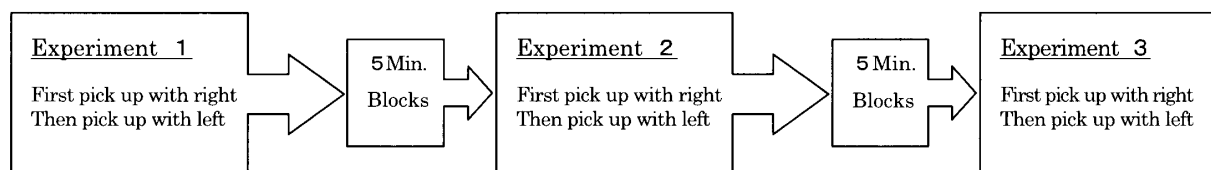


Figure 2. Experimental procedures Experiments 1, 2, and 3 were assigned at random.

- 7) The grip object was covered by a screen and the film case in the grip object was always exchanged so that the subject could not visually predict the weight of the grip object.

4. Analysis Method

The average contact surface pressure of the thumb and index finger measured from two probes was designated as the contact surface pressure obtained in the experiment. The peak value of the contact surface pressure for right and left under each condition was compared and analyzed. Paired-t Test was used to evaluate differences between the contact surface pressures of conditions 1, 2 and 3. The level of significance was set at 0.05. Statistical software Statcel (OMS publishing Inc) was used for analyses.

Results

- a. Comparisons among Conditions 1, 2, and 3.

The contact surface pressure of the left hand at the time of picking up the light object under Condition 1 was 0.95 ± 0.26 kPa (mean $\pm$ SD). On the other hand, the contact surface pressure of the left hand at the time of picking up the light object of the same weight in Condition 2 was 0.79 ± 0.27 kPa (mean $\pm$ SD). Significant difference ($P < 0.05$) was observed (Table 1) The contact surface pressure after picking up the heavy weight with the right hand was higher

than that measured after picking up the light object with the right hand.

- b. Comparison within the same Condition.

The contact surface pressure of the right and left hands when picking up either a light or a heavy object were compared. The contact surface pressures under Condition 1, the heavy object picked up with the right hand and the light object picked up with the left hand, were 1.09 ± 0.12 kPa (mean $\pm$ SD) for the right hand and 0.95 ± 0.26 kPa (mean $\pm$ SD) for the left hand; showing a significant difference between them ($P < 0.05$). On the other hand, the contact surface pressures under Condition 2, the light object picked up with the right hand and the same light object picked up with the left hand, were 0.81 ± 0.25 kPa (mean $\pm$ SD) for the right hand and 0.79 ± 0.27 kPa (mean $\pm$ SD) for the left hand. No significant difference was observed between them. Furthermore, the contact surface pressures under Condition 3, the heavy object was picked up with the right hand and the same heavy object was picked up with the left hand, were 1.1 ± 0.11 kPa (mean $\pm$ SD) for the right hand and 1.13 ± 0.13 kPa (mean $\pm$ SD) for the left hand. Again, no significant difference between right and left was observed (Table 1).

Discussion

When we pick up an object, the grip force is adjusted to the nature of the ob-

Table 1. Contact surface pressure (CSP) of right and left hands under 3 conditions.

	Condition 1		Condition 2		Condition 3	
	Right/heavy	Left/light	Right/light	Left/light	Right/heavy	Left/heavy
CSP (kPa)	1.09 ± 0.12	0.95 ± 0.26	0.81 ± 0.25	0.79 ± 0.27	1.10 ± 0.11	1.13 ± 0.13

ject; thus, we can hold a 350 ml glass of juice without dropping it, and we can hold an empty paper cup without crushing it. Many studies have investigated grip force; demonstrating that the grip force is influenced by various factors, such as visual information^{4,5)}. Gordon et al reported that humans predict the characteristic of an object using visual information in order to effectively apply appropriate lifting power or grip force. Moreover, many studies have reported that grip force is influenced by the physical characteristics of the object, such as size⁵⁾, the weight of the object,^{6,7)} and how easy it is to grip the object^{1,7,8)}.

As described above, grip force is influenced by the physical characteristics of the object (size, weight of the object, how easy it is to grip the object) to be picked up. However, the film cases used in this experiment offered no distinguishable clue as to whether they were heavy or light because they were of the same size and appearance. Moreover, since the objects were picked up by the same subject when either heavy or light objects were picked up, the trials were considered to have been conducted under identical conditions regarding the visual appearance, the size of the hand, and how easy it was to grip the object. It is suggested that any differences in contact surface pressure resulted from the difference in the weight of the object.

We compared the contact surface pressure of the left hand with grip motion under Condition 1 with that under Condition 2. There was a significantly larger value in Condition 1 ($P < 0.05$). The weight of the object, the size of handle and the handle material were the same. The difference between the two conditions was either having previously picked up the heavy or the light object with the

right hand. Therefore, the contact surface pressure while picking up a light object was influenced by an experience of picking up a heavy object previously. Johansson and Westling¹⁾, McCloskey²⁾, and Kinoshita et al³⁾ have reported that in the human precision grip movement, grip force is exerted according to the weight. The weight sensation being memorized during the motion of picking up strongly affected the grip force of the next motion of picking up. They reported that if the sensation of touch/pressure of the fingers is blocked by anesthetization, the grip force is increased and the subject cannot appropriately respond to the weight change; however, this was an experiment for the upper limbs of the same side. The results of our study demonstrate that "a difference in the condition of whether a heavy or light object was gripped by right hand", have an influence on the next grip motion of the left hand. That is, we believe that the experience of picking up a heavy object with the right hand results in an excessive force at the time of the next motion with the left hand.

The following points were considered by examining the difference between right and left within the same condition. It has been reported that there is no difference in the control of power between right and left upper limbs as no constant tendency is observed,⁹⁾ and there is no difference between right and left regarding the ability to estimate weight¹⁰⁾. A significant difference was observed in the present study between the right and left contact surface pressure in the motion to pick up a heavy container with the right hand then pick up a light container with the left hand. It is conjectured that the force was reduced due to the feeling that the object was unexpectedly lighter than

the object of first trial. On the other hand, no difference between right and left was observed in the motion of picking up a light container with the right hand and then picking up a light container with the left hand, or picking up a heavy container with the right hand and then pick up a heavy container with the left hand. This is probably a demonstration that the subject exerted the same force in the right and left hands as there was no difference in weight. The contact surface pressure of the left hand in Condition 1, is significantly higher than that of the left hand in Condition 2. From this, it is suggested that the difference depends on whether or not the initial object in the right hand was heavy or light.

People tend to pick up objects of the same appearance with the same grip force, but if the weight is different from the weight they judge, they will change grip force in the movement. In present study, since the subject perceived that two objects were the same weight, they picked up the objects with same grip force. Human movement is controlled with prospect. The information about weight that was obtained from the other side was used for the prospective assessment. Kawai et al⁶⁾ reported the result of an experiment when an object was picked up and then another object of different weight was picked up; a significant influence was observed in the initial phase of the second picking up, and the amount of the excess force applied depended on the weight of the first object. It was reported that the excess force applied is greater when holding a heavy object first and then holding a light object, than holding objects of the same weight. The excess force becomes even greater if holding a heavy object first and then again holding a heavy object.

Furthermore, it has been reported that a greater grip force was exerted, as a continuing greater grip force is expected immediately after experiencing a heavy weight because of the after-effect (sustained effect)¹¹⁾. The demonstrated output of grip force based on the memory of the weight sensation is mostly eliminated within about 10 seconds after the start of holding, due to the feedback signal generated by the peripheral nervous system.

In the present study, change over time was not followed and only the peak value of the contact surface pressure was recorded. The times at which subjects picked up objects were different for each of the subjects in our experiments; therefore, we couldn't compare changes over time. However, it can be inferred that the peak of the contact surface pressure was observed in the initial phase of the motion by the left hand; this in accord with the results in Kawai et al.

It is suggested that functional training of paralytic upper limbs can efficiently be undertaken when consideration is given to the effects detailed above. Thus a patient can be trained by putting out surplus force to an affected hand following moving a very heavy object with the sound hand.

Various studies have reported how power is controlled in humans while picking up and holding an object against gravity. Westling and Johansson⁷⁾ reported that grip force consists of the minimum power required for the grip motion (Slip Force) and excessive power (Safety Margin Force). Slip Force did not change, but the Safety Margin Force increased when subjects picked up a light object after picking up a heavier object. It will be necessary to continue investigations regarding when and how much excess force is demonstrated under different con-

ditions.

Conclusion

When a subject picks up a heavy object with the right fingers, and then picks up a light object with the left fin-

gers, excess force is generated. It is clear that information regarding the force generated by fingers during the first motion-performed by one side of the body influences the subsequent motion performed by the other side.

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