Analysis of Weight Perceptual Mechanism Based on Muscular Motion Using Virtual Reality

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Abstract - In this paper, by focusing on weight perception, we attempted to clarify a perceptual mechanism using functions of the haptic interface. We especially examined the weight perceptual mechanism when the weight of an object suddenly changed, which does not take place in our natural life. This experimental condition can only be realized by using the advantage of the haptic interface. The results show the difference in the perceptual threshold due to addition and reduction of the weight. Moreover, the results indicate that subjects can also correct the supporting force corresponding to the sudden change in the weight when they could not sense the change. Namely, it implies that subjects adjust the supporting force under an imperceptible state, which may indicate an interesting muscular motion under a state of unconsciousness.

Keywords: Haptic interface, virtual reality, weight perception, muscular motion.

1 Introduction

In daily life, human beings can recognize their circumstances by transmitting stimuli received by their sense organs to their brain. For example, we can recognize the shape and texture of an object by touching it so as to stimulate a tactile sense organ. The field of psychology focuses on the functions of these sense organs and perceptual mechanisms as essential factors that can clarify one of the complex brain functions. In fact, some studies have been reported on such a topic from some interesting viewpoints[1]. In the previous studies, the feedback loops of the cognitive/perceptual and sensorimotor systems are considered as the same function. However, recent studies put forward an attractive hypothesis that these feedback loops are separated and function individually[2]. For example, there is an unique phenomenon referred to as "size-weight illusion (Charpentier effect),” according to which human beings never fail to perceive smaller object to be heavier when the two objects with the same weight but different volumes are compared[3]. J. R. Flanagan and M. A. Beltzner disproved the hypothesis that this phenomenon is caused by a mere mismatch between the weight prediction by vision and actual weight perception. They suggested that the function of the sensorimotor system is separated from the cognitive/perceptual system[2]. If the cognitive/perceptual and sensorimotor systems function individually, which may depend on the functions of the cerebellum and cerebrum, this hypothesis should be evaluated experimentally. However, it is very difficult to conduct these types of perceptual experiments because it is practically tough to frequently change both the experimental method and conditions in real world. Such changes are usually unavoidable in most research studies. Therefore, we have proposed the use of the haptic interface as an experimental tool concerning force/tactile perceptual experiments[4][5]. The haptic interface is a virtual reality technology; it can present arbitrary forces to users and easily change experimental conditions. If virtual reality can be used as an experimental environment, it becomes possible to smoothly change such experimental conditions and extend the discussion on human perceptions to a special environment such an outer space. One of the prominent advantages of the haptic interface is that it can also adjust all motions of the subjects. Moreover, the sensing capabilities of the haptic interface are very effective for motion analysis of the subjects when they just perceived the change of stimulus. In our previous studies, we have examined the possibility of using haptic interface for physical experiments about illusion phenomena[4][5]. Their results of “horizontal-vertical illusion” and “size-weight illusion” indicate an excellent effectiveness of the haptic interface in this force perception field.

In this paper, we study the weight perceptual mechanism by using the haptic interface; this system...
enabled the realization of a special experimental condition such as sudden weight change. This special experimental condition, which cannot be realized in practice, may offer the possibility of obtaining a key mechanism in the weight perceptual mechanism field.

2 Experimental method

In this study, we examined the weight perception of human beings by use of the haptic interface when the virtual weight, which was generated by the haptic interface and presented to the subjects, was suddenly changed. We conducted this experiment on five subjects who had no prior information regarding the true aim of the experiment. The details of the method and procedure are as follows.

2.1 Experiment 1: Difference threshold

We investigate the difference threshold of each subject for a rapid weight change when a load force given by the haptic interface was suddenly added or reduced. The difference threshold is a psychological term; in this study, it means the boundary stimulus whether the subjects can perceive the weight change or not. In this experiment, the haptic interface was grasped by both the thumb and index finger of the subject.

2.1.1 Location of the experimental system

Figure 1 shows an actual picture of the experimental environment surrounding the subject. In this experiment, the robot finger system is reconstructed as the haptic interface. The robot finger is located on the side of dominant hand. It gives the load force in the vertical direction and measures the responses of the subject, such as supporting force and motion, by using equipped sensors. On the other side, a radio type optical mouse of a computer for control is located so that the subject can inform the operator by clicking it about whether or not he can perceive the weight change. Here, the operator means the person who conducts the experiment and instructs the subject. In addition, a liquid crystal display located in front of the subject presents 3D graphics of a virtual environment. It simultaneously shows a virtual object motion with the robot finger motion when the subject operates the robot finger. These functions can realize a virtual reality when the subject lifts an object.

2.1.2 How to provide a stimulus

In this experiment, we prepared two standard stimuli (standard weights), which weight at 200 g and 400 g. The dimensions of the blocks are $48 \times 48 \times 48$ mm and $60 \times 60 \times 60$ mm; they are cube and drawn with real size in the graphic display for the subject. Their densities are close to the density of aluminum, i.e., they are modeled on the objects that can exist in the real environment. Moreover, the graphics of the grip is attached to the top of virtual object, as shown in Figure 2 (a). The grip moves simultaneously with the virtual object in the graphic display so that the haptic and visual information are in agreement when the subject lifts the haptic interface.

Further, a weight change rule is described. The minimum value of the weight change is set at 1% of standard weights; it is presented by 2 g or 4 g in each case. The weight is added or reduced regularly by 0% to 20% under this rule. The adding and reducing load phases are changed by turns after 20 lifts. In this study, we analyze the difference in the responses between active (adding) and passive (reducing) load conditions.

2.1.3 How to lift the virtual object

Initially, the subject holds the grip of the robot finger and lifts the haptic interface (virtual object) vertically until it reaches the height of 6.5 cm from the initial position. (This height is also a trigger that activates a timer for the start of the experiment and records.) At this time, the elbow of the subject is placed on a base whose height is variable. This constraint unifies the motion of all subjects by the exercise of the forearm and wrist. A signal shown at a corner of the graphic display is changed from red to green when the haptic interface attains the required height of 6.5 cm, as shown Figure 2 (a). This change of the signal enables the subject to recognize whether or not he satisfied the height condition. The subject then maintains the height for 5 s. After 5 s supports, the weight is changed automatically within the next 3 s. Hence, neither the subject nor the operator can precisely predict the moment at which the weight changes. Thus, the prediction of the subject is completely eliminated.
2.1.4 Experimental procedure

In this section, the procedure of the experiment concerning the difference threshold is described in detail from the flow chart in Figure 3. First, a standard stimulus is given to the subject by using the haptic interface. The subject is then asked to grasp and lift it to the required height of 6.5 cm. In this position, the subject supports the haptic interface for 5 s. Second, the subject judges whether or not he can perceive the change as the load force is suddenly changed within the next 3 s. The operator can then observe the moment by clicking the mouse when he could perceive the weight change. The judgment delivered after 3 s from the time of the weight change is ignored because of the possibility of the accidental judgment. The operator records this judgment as “YES” or “NO.” Finally, the subject returns to the haptic interface to the initial position and releases its hold. After a series of process is repeated 20 times, it proceeds to the next condition. In the next condition, the operator changes the adding or reducing load phases. Otherwise, a series of procedure are repeated until the end condition is satisfied. A total of 800 trials are conducted including the adding and reducing load phases for each subject. Moreover, in order to eliminate the influence of muscular fatigue, a break 20 min is taken after 200 lifts. During this period, all the subjects are allowed to behave freely; most of them returned to their office or laboratory work.

In this experiment, the operator can change all the experimental conditions by pressing a few buttons of the keyboard. The operator can also observe almost all the states of the subjects, such as perceptual action, as shown in Figure 2(b).

2.2 Experiment 2: Examination of response

From the results of the experiment in section 2.1, we can obtain the difference threshold of each subject for the sudden weight change perception. This threshold can separate the perceptible stimulus from the imperceptible stimulus in the absolute threshold. In this study, the perceptible stimulus means the weight change over the threshold; if the stimulus is given to the subject, he can recognize the weight change. While, the imperceptible stimulus means the weight change under the threshold; even if the stimulus is given to the subject, he cannot recognize the weight change. By the use of the difference threshold results, we also attempt to clarify the weight perceptual mechanism by analyzing the responses of the subject in both the perceptible and imperceptible regions. In detail, after a sufficient and suitable interval since performing the experiment described in the section 2.1, the same subjects are again asked to lift the haptic interface and support it. Thus, using each difference threshold, 20 trials were conducted in case of under threshold and over threshold; its process is the same as the procedure in section 2.1.3. During the experiment, the change of position, load force etc. was also recorded by use of the sensing functions of the haptic interface. Using this information, we attempted to analyze the difference in the responses between under and over thresholds.

3 Experimental system

3.1 Hardware system

Figure 4 presents a schematic diagram of our experimental system, which realizes the experimental environment as described in chapter 2. It principally consists of three component parts, which are a robot finger system, a motor driver system and a computer. Its main component is a robot finger system with 3 D.O.F. It has a three-directional force sensor and an original one-directional grip force sensor on its tip. These can ensure the measurement of each force until a maximum of 10 N and 40 N, respectively. The original strain-gauge type grip
force sensor can measure the force by pressuring it between the thumb and index finger. Each joint has a rotary encoder to measure the rotation angle. Moreover, this system has a visual support system with OpenGL, which presents the virtual environment. By using dual display function that is a standard function of Windows OS, we can divide into two graphics as shown in Figure 2. Thus, the sampling time is set at 5 ms because a single computer must process both control and drawing the graphics.

3.2 Control algorithm

In this experiment, this system requires a stable control because of the precise measurement of responses with very small weight change, such as 2 g or 4 g. We applied a simple control algorithm based on the force-servo mechanism to the robot finger, as shown in Figure 5, which can generate the required force. The desired weight is produced by the drive of the first and second joint actuators in order to avoid the useless motion of third actuator at the tip. It is also ensured that this system can display the load force until approximately 7 N. An arbitrary weight display in the vertical direction can be realized by giving desired force, as shown in equation (1). Here, \( m \) is virtual mass and \( g \) is acceleration due to gravity.

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f_d = \begin{bmatrix} 0 & 0 & mg \end{bmatrix}^T
\]

4 Experimental results

4.1 Difference threshold

Figure 6 (a) and (b) show the typical results in both the adding and reducing load phases performed by a certain subject. The horizontal axis indicates the weight changes rates. The vertical axis represents the percentage of correct answer for each weight change. In this study, we define the difference threshold as 75% of the proportion, at which the subjects can certainly recognize the change over it. The results of five subjects show that the average difference threshold for the sudden weight change is approximately 9% in the adding load phase and approximately 11% in the reducing load phase for both cases. Therefore, it should be noticed that the difference threshold is smaller in the adding load phase, which implies that the perception becomes sharper in this phase. Generally, it is known that the perception of human beings becomes sharper during an active motion. In the adding load phase, it is assumed that the response becomes more active to the opposite direction of the gravity since human beings must use the active action against the gravity. Therefore, this active mechanism might affect the weight perception of the subjects. We also confirmed that these results follow the famous “Weber’s law”: the ratio of standard stimulus to its difference threshold is approximately constant even if the magnitude of standard stimulus is changed.

4.2 Supporting force and its rate of change

In this section, we examine the supporting force pattern of the subject, which is shown in Figure 7. Figure 7 (a) and (b) show the results when the standard stimulus is set at 200 g. Since the tendency is almost the same as in case of 400 g, its results are not shown in this paper. The most important aspect in this case is that although the subject could not notice the change of the stimulus, he also responded under the threshold, i.e., it indicates a possibility that he unconsciously exerted a force against the weight change. However, these results do not exaggerate the difference between the conscious and unconscious motions. We then examined its rate of change. Its results are shown in Figure 8, whose horizontal axis indicates the transition of time and vertical axis indicates a supporting force rate. As shown in Figure 8, the large change takes place over the threshold in both the phases. It implies that the magnitude of the supporting force rate divides the stimulus into the perceptible and imperceptible stimuli. These results show that the subject immediately adjusts the motion to the rapid weight change in the perceptible stimulus because he produces the sharp supporting force.
change due to the sudden weight change as shown in the blue line of Figure 8. Although there is no remarkable change in the supporting force rate in the imperceptible weight change, the subject gradually responds to the weight change as shown in Figure 7, which implies that he also generates the supporting action under the threshold. The muscular motion on the forearm or wrist may result in these actions. In the previous studies, there are also arguments that the grip motion of fingertips may lead to this adjustment[6]. Namely, the elastic deformation of the finger skin may generate the grip force to the weight change. So we examine this grip motion in the next section.

4.3 Grip force and its rate of change

Further, we also paid attention to the grip force and its rate of change. We assumed that if the weight perception depends on the elastic deformation of skin, an extremely large change occurs in the grip force after the weight change, especially over the threshold. This is because it is assumed that the deformation or slip at the fingertips must increase at that instant. Otherwise, there must be no such unique change in the grip force. In fact, the results of two patterns were obtained. One of them exhibited almost no change; however, the other showed an extreme change immediately after the sudden change. Figure 9 shows the results in case of 200 g in the adding load phase, which took place above the difference threshold value. In Figure 9, the black line shows the force required to avoid slip, which is calculated by a friction coefficient between the fingertips and the grip. These results show that when the margin between the grip force and the required force to avoid slip is sufficient, as in pattern I, notice that an extremely large change does not occur. On the contrary, an extremely large change occurs when the margin is insufficient, as in pattern II. In this case, it implies the possibility that human beings
perceive the weight change by the deformation of skin, which senses the feeling that the slip has been caused between the fingertips and the grip. In this case, the pattern of the supporting force referred to in the section 4.2 may be dependent on the skin deformation at the fingertips. However, human beings tend to grasp the object with a sufficient force in order not to drop it, as shown in the experiment[7]. Generally, human beings may perceive the weight change by a muscular motion.

5 Example of application

From the above discussion, the results imply the possibility that human beings can recognize the weight change of an object by perceiving its rate of change. We investigated when the subject can notice the weight change due to a gradual decrease in the weight from the initial weight (1.96 N), whose rats of change are –0.2 N/s, –0.4 N/s and –0.6 N/s. Figure 10 shows a typical result obtained by a certain subject. With regard to the rate of –0.2 N/s, the subject could notice a change in the weight at 1.2 N. These results indicate that the subject cannot notice the weight change up to the large difference, as the rate of change becomes smaller. Therefore, it shows that it becomes difficult for human beings to perceive the change when the weight of the object is changed gradually. Therefore, we believe that if the users of the haptic interface can be deceived with this mechanism, we may be able to produce the weight perceptual illusion artificially.

6 Conclusions

In this study, we examined the weight perceptual mechanism through the physical/virtual experiment using the haptic interface. Through the results of analysis using the sensing functions of the haptic interface, it is inferred that human beings can perceive a weight change with the magnitude of its rate. When a subject cannot perceive its change under the threshold, he may unconsciously adjust his muscle command to the weight change, which yields interesting results. There are many arguments regarding this such as the muscle and skin can detect this weight change information. In particular, we investigated the grip motion effect, whose results show that slipping feeling due to the skin deformation may lead to the weight change perception when the grip force is insufficient. On the other hand, when the grip force is sufficiently large, the weight change perception doesn’t arise from the slipping feeling in the skin. These results imply that human beings change the sense organ to perceive the weight change according to the situation. In addition, we proposed a weight illusion method as a virtual reality application. This study may shed further light on virtual reality technologies.

In conclusion, the basic perceptual mechanism of a sudden weight change is clarified by the use of the haptic interface, which is an excellent experimental system for this force perception field since it enables the experimental conditions to be changed easily.

References


