Presenting the sensation of flying with flapping virtual wings independent of the limbs

Ken Endo[1] and Ikuo Mizuuchi[1]

***Abstract*— Since ancient times, people have longed to fly in the sky. Actual flying involves risks and costs, but using a VR device makes it easy to experience flight. In this research, we proposed a method of presenting the sensation of manipulating the wings without using the limbs and a method of transmitting the force acting on the wing to humans. Unlike studies that presents the sensation of flapping wings by moving the arms, new applications that use the limbs during the flight experience can be expected by flying without moving the limbs. From the experiment, it was confirmed that the operation by static muscle contraction is also effective for operationing wings. It was also shown that the haptics presentation using EMS has a higher overall evaluation. Finally, we obtained the result that the body image expansion of the virtual wings which proposed in this research is possible.**

Fig. 1: Flying with flapping virtual wings independent of the limbs

I. INTRODUCTION

Since ancient times, people have longed to fly in the sky. Until today, we have had a flight experience by using vehicles such as airplanes and hang gliders. However, actual flying involves risks such as crashes and costs such as fuel. By using VR system, these can be avoided, and makes it easy to experience flight.

Many studies have been conducted to give a sensation of "flying" using VR devices. Research on the sensation of falling generated by visual stimuli and a proposal for a flight experience device using a body assistance mechanism are examples.

Regarding research that gives a sensation of "flying with flapping", research has been conducted on a device that allows the user to board a large control device and experience a bird in flight [8]. This method has disadvantages such as the need for a large scale device and the limitation of limbs movement. In addition, there are still few studies on giving the sensation of flying with flapping one's wings. In general, studies on giving the sensation of flying by becoming a bird have been conducted, and studies on giving the sensation of flying by becoming a creature with wings independent of its limbs, such as a flying lizard, have not yet been focused on.

Fig. 1 shows how they flying with flapping virtual wings independent of the limbs. In this research, we propose a method of presenting the sensation of flying with flapping virtual wings independent of the limbs as shown in Fig. 1. By not using limbs movements, it is possible to use hands and feet during the VR flight experience, such as throwing an object while flying, whick is expected to expand the range of the VR flight experience.

[1] Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, 2-24-16, Naka-cho, Koganei-city, Tokyo, Japan {ken,ikuo}@mizuuchi.lab.tuat.ac.jp

II. EXPANSION OF BODY IMAGE

In this research, two elements are important: to make humans feel "wings" that do not originally exist, and to present the sensation of "flying with flapping with one's wings". In order to present these sensations, we focus on the expantion of the body image.

A. Body image

Humans have the ability to perceive their own body shape, which is called body image [5]. It allows us to ditinguish between ourselves and others.

Besides, there are two concepts that are closely related to the body image: sence of self-ownership and self-agency. Sence of self-ownership is the sensation or experience that one's own body parts belongs to one's own body. Sence of self-agency is the sensation or experience that one is performing and action by oneself and that one is in control of the body parts.

The sense of self-ownership and self-agency are closely related to the formation of the body image. Therefore, it is considerd that the following elements in this research can be satisfied by flying with a virtual wings body image, that is by expanding the body image and operating.

- To make humans feel "wings" that do not originally exist (Sense of self-ownership)
- To present the sensation of "flying with flapping with one's wings" (Sense of self-agency)

B. Body image expantion

The body image may change dynamically to parts other than the self. This is called body image expantion. An example of body image expansion is to treat a tool (for example, a tennis rackaet or a baseball bat) held in the hand as if it were a part of one's own body without being aware of its shape, and hit the ball back [3].

Body image expansion can be broadly categorized into two types: one is sensory remapping, such as the Rubber Hand Illusion (RHI), and the other is the dynamic expansion of the boy image during tool use mentioned above (Embodiment of tools).

C. Rubber Hand Illusion

The Rubber Hand Illusion is the illusion that we feel the rubber hand as if it were our own hand. It is an illusion phenomenon in which a person perceives a haptics stimulus on a rubber hand after gibing a synchronized haptics stimulus to a real hand hidden from field of vision and a rubber hand in front of the eyes for about 2 to 20 minutes. One of the characteristics of RHI-based body image expansion is that the original body part and the remapped part cannnot coexist.

D. Embodiment of tools

There is a neurophysiological study on the embodiment of tools using Japanese macaque monkeys that showed the expansion of body image by tool use. By observing the activity of bimodal nuerons with hand somatosensory receptors and visual receptors near the hand in the parietal cortex of Japanese macaque monkeys during tool use, and showed that the monkey's body image extendetd to the tip of the tool [6].

E. Body image expantion approach

In this research, we focus on the body image expantion to tools (embodiment of tools).

It is known that tele-robots and avatars, which have similar degrees of freedom and dynamics to humans, can be recognized as part of the body by perfectly synchronizing their body movements, such as the generation of the sensation of being transported, as in the RHI, or the embodiment of tools.

It has also beeen shown that the temporal coincidence of sensory information (such as visual and haptics) is highly important in the generation of the RHI [4].

Therefore, the temporal coincidence of sensory information is considerd to be important also in the embodiment of tools. On the other hand, spatial coincidence is considered to be flexible, and there are cases where the subject responds as if the subject had struck his or her hand when hitting the rubber hand with RHI occurring [1].

As described above, body image expantion (embodiment of tools) can be expected by integratin multiple senses and matching the sensory information presented in time. In this study , we try to expand the body image as shown in Fig. 2. We attempted to integrate multiple senses by giving a instruction to move the wing from the human to the wing, and transmitting the sense of having wings, the sense of flying with wings, and the sense of air resistance. From the above, we present the sensation of flying with flapping virtual wings independent of the limbs.

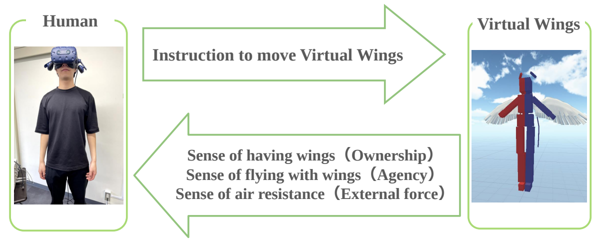


Fig. 2: Method of body image expansion

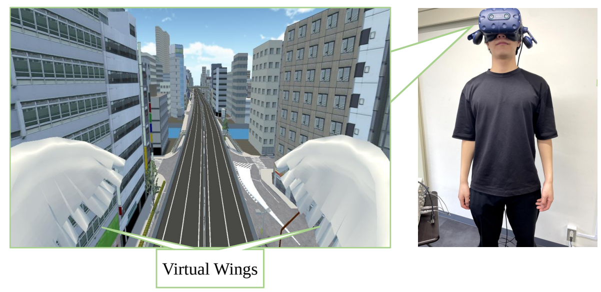


Fig. 3: Presentation of visual information by using the virtual environment

III. HOW TO PRESENT WINGS INDEPENDENT OF LIMBS

A. Information transmission from humans to virtual wings

First, we describe a method of giving instruction from a human to virtual wings to move the wings. There are several methods of presenting information from a human to a system in a VR space, such as using a controller, gestures, or biological signals. Since the purpose of this study is to control the wings with something other than the limbs, we use biological signals that can be measured without limbs movement, instead of controllers that mainly use the hands or gesture that require limbs movement. In addition, the virtual wings is controlled by EMGs, which are easy to obtain numarical values among biological signals.

B. Information transmission from virtual wings to humans

Next, we describe a method of providing information from the virtual wings to a human. The five senses can ve mentioned as senses that work on humans. Among them, visual and haptics senses are often used as the information that works on humans in body image expantion. This indicates that the integration of visual and haptics senses is effective in body image expansion. In this research, we present information from virtual wings using both visual and haptics senses.

1) Presentation of visual information: The visual presentation is performed by outputting images created by PC software (Unity) to a visual display as shown in Fig. 3.

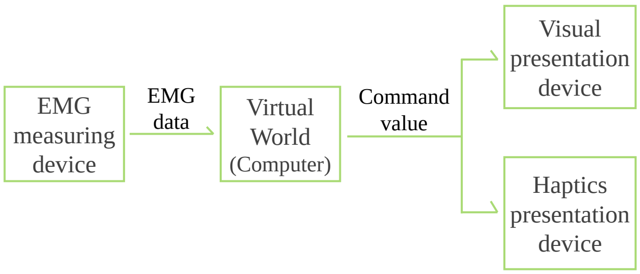


Fig. 4: Experimental environment system

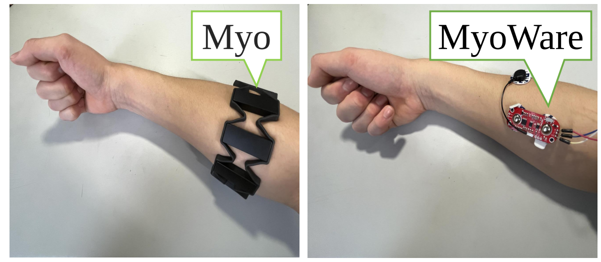


Fig. 5: EMG devices (Left: Myo, Right: MyoWare)

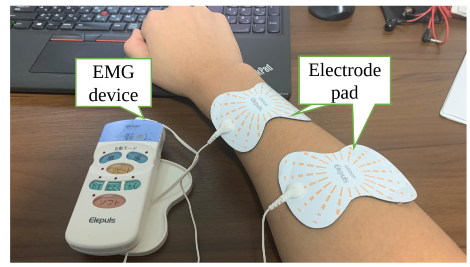


Fig. 6: EMG device (Omron HV-F122)

The output image shows it is moving in the air and wings growning from one's back.

We use an illusion called vection (self-induced self-motion sensation) to present the appearance of movement in the air [2]. Vection is the illusion that a body moves in a direction opposite to the direction of motion of the stimulus when a uniform motion stimulus is presented over most of the visual field.

As for the presenting growing wings from the back, when the user looks back, one can see the part of the wings growing from the back. Furthermore, when the wings are flapped, the appearance of expanding and closing the wings in the field of view is presented.

2) Presentation of haptics information: In haptics presentation, by presenting the haptics sensation at the root of the wings, the sense of having wings, the sense of flying with wings, the sense of air resistance are presented. This encourages the expansion of the body image through the presentation of haptis sensations to a certain area, similar to the expansion of the body image to the tip of a stick held by the hand in the embodiment of tools.

Besides, we also prepare two haptics displays: one using vibration and the other using electrical stimulation.

Haptics display using vibration presents vibration by an eccentric motor. Haptics display using elecal stimulation is called EMS (Electro Myo Stimulation) is a method of stimulating muscle contraction by applying electrical stimulation to muscles and motor nerves to simulate haptics sensation.

In this research, haptics sensation is generated by muscle contraction using EMS equipment, and information from the wings is presented.

IV. PRE-EXPERIMENT USING THE PROPOSED METHOD

Using the proposed method of body image expansion, we examine the methods of manipulation and presentation, the position of manipulation and presentation, and evaluate each combination.

A. Exprimental environment for subjective evaluation

We describe the experimental environment for the subjective evaluation experiment. As shown in Fig. 4, we use a system that sends the values measured by the electromyography device to the software (Unity) on the terminal, and operates the visual and haptics presentation devices from Unity.

First, two EMG measuring devices, Myo (Thalmic Labs, Fig. 5. left) and MyoWare (Advancer Technologies, Fig. 5. right) , are prepared to compare manipulation by gesture and force.

Next, for haptics display, we prepare haptics presentation devices using vibration and EMS. The vibration function of Myo is used for vibration haptics presentation, and the Omron HV-F122 (Fig. 6) , a low-frequency treatment device, is used for EMS haptivs display.

Then, for the visual presentation device, two types of visual presentation will be prepared, one using an LCD monitor and the other using a Head Mounted Display (HMD) , in order to compare the third-person perspective and the first-person perspective. The LCD monitor is GW2765HT (BenQ), and the HMD is Quest from Meta.

B. Examination of operation and presentation methods

Table 1 shows the comparison items, where FPP is First Person Perspective and TPP is Third Person Perspective.

1) Comparison of wings operation methods: First, we compare the manipulation methods of the wings. Manipulation methods using EMG can be classified in to gesture (dynamic muscle contraction [9]), which are movements accompained by joint movements, and manipulation by force

TABLE I: Comparison items

Comparison item	Wings operation	Haptics display	Visual display
Wings operation	Gesture/Strengthen	Vibration	TPP
Haptics display	Strengthen	Vibration/EMS	TPP
Visual display	Strengthen	EMS	TPP/FPP

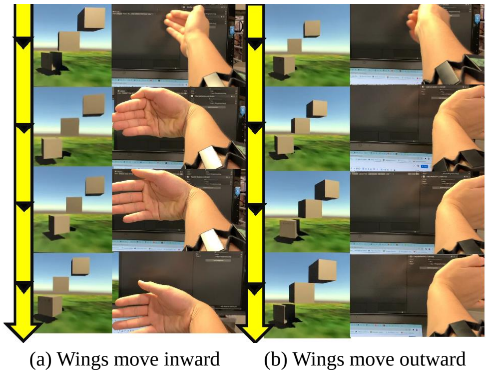


Fig. 7: Manipulation of virtual wings skeleton using Myo

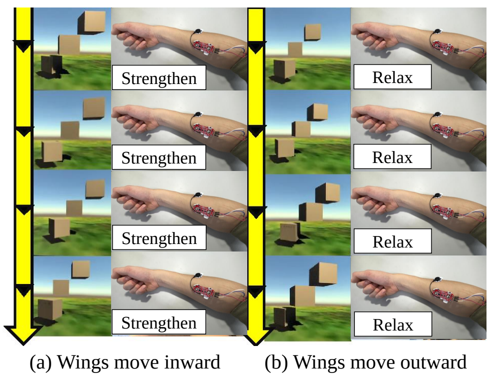


Fig. 8: Manipulation of virtual wings skeleton using MyoWare

or static muscle contraction, which does not involve joint movements.

Fixing the conditions of haptics and visual presentation and comparing manipulation by gesture and force (Table 1).

When Myo is used as the myoelectric measurement device (manipulated by gesture), the virtual wings is designed so that when the wrist is bent inward, the wings also flaps inward, and when the wrist is opened outward, the wings also opens outward, as shown in Fig. 7. The haptics sensation is presented in such a way that the Myo attached to the forearm vibrates in time with the inward flapping of the wings.

In the case of using MyoWare (manipulation by force), the wings are designed to close when forces is applied and to open when relaxed, as shown in Fig. 8. The haptics presentation is made by vibrating Myo attached to the arm when the wings flap inward. MyoWare measures the forearm, chest, and shoulder as the measurement sites, where the forceful motion is easy.

As a result of the verification, we confirmed that it is possible to operate the virtual wings using force as well as gestures, which is a common method of operating VR applications, as intended by the pilot.

2) Comparison of haptics presentation methods: Next, we compare the haptics presentation methods using vibration and EMS.

We fixed the conditions of wings manipulation and visual

TABLE II: Results of an experiment using vibration as a haptics presentation

Position(Sensing/Haptics)	Arm/Arm	Chest/Arm	Shoulder/Arm
Sense of having wings	1	1	2
Sense of meneuvering the wings	4	4	4
Sense of air resistance	4	4	4
Sense of flying with wings	1	2	2

TABLE III: Results of experiments using EMS as haptics presentation

Position(Sensing/Haptics)	Arm/Arm	Chest/Arm	Shoulder/Arm
Sense of having wings	1	2	2
Sense of meneuvering the wings	3	3	4
Sense of air resistance	3	3	3
Sense of flying with wings	2	2	3
Position(Sensing/Haptics)	Arm/Abs	Chest/Abs	Shoulder/Abs
Sense of having wings	3	3	3
Sense of meneuvering the wings	3	3	4
Sense of air resistance	4	4	4
Sense of flying with wings	3	4	3
Position(Sensing/Haptics)	Arm/Back	Chest/Back	Shoulder/Back
Sense of having wings	5	5	5
Sense of meneuvering the wings	3	4	5
Sense of air resistance	4	4	4
Sense of flying with wings	4	5	5

presentation, and compared the presentation using vibration as a haptics sense with that using electrical stimulation (Table 1). We used MyoWare to manipulate the wings so that they closed when the forearms, chest, and shoulders were relaxed. For the visual presentation, the wings movements (Fig. 9) are shown on the LCD display from a third-person perspective.

Table 2 and Table 3 show the subjective evaluation of the information presented from the virtual wings to the human during the experiment using the Likert scale in five levels when vibration and electrical stimulation were used as haptics presentation.

The first row of Table 2 and Table 3 shown the results of the haptics presentaion on the forearm, respectively. Teh first row of Table 2 and Table 3 show the results of haptics presentation to the forarm. Therefore, it can be said that not only vibration but also electric stimulation is useful for haptics presentation.

In addition, Table 3 shows that the overall evaluation of both myoelectric measurement and haptics presentation was higher in the torso than in the limbs (arms). Therefore, it is thought that the sensation of flying with flapping can be presented more strongly when both myoelectric measurement and haptics presentation are performed on the torso than on the limbs.

3) Comparison of visual presentation methods: Finally, we compare the visual presentation methods. We prepared an LCD display and an HMD as visual presentation devices, and presented images from the third-person and first-person viewpoints, respectively.

The operation method of the wings and the conditions for haptics presentation are fixed, and a comparison is made when the third-person viewpoint and the first-person viewpoint are used as visual presentation (Table 1). The wings are designed to close when the forearms, chest, and shoulder are Strengthen, and to open when they are relaxed. Haptics sensation is presented to the forearms, chest, abdomen, and back using EMS equipment (Fig. 6).

We found that the first-person perspective induced a stronger sense of wings growing from one's own body than the third-person view, and that the third-person view induced a sense of manipulating remote wings rathrer than one's own wings, and a sense of remapping like the RHI rathrer than embodiment of tools, it is not a sense of embodiment. The first-person perspective was found to be more effective than the third-person perspective in embodiment of tools.

C. Examination of operation and presentation position

As a result of examining the operation and presentation methods, we found that the presentation of the sensation of flapping wings differs depending on the operation position (myoelectric measurement position) and the haptics presentation position. Therefore, in order to efficiently compare the differences between the two positions, we selected candidates for the myoelectric measurement and haptics presentation positions.

1) Examination of operation posotion: 7 In the case of the body, the chest, abdomen, shoulders, and buttocks are the most common sites for static muscle contraction. In myoelectric measurement, if there is a lot of subcutaneous fat at the measurement point, the amplitude of the myoelectric potential is attenuated and becomes unclear. Therefore, it is necessary to select an area with relatively little subcutaneous fat as the myoelectric measurement location. In order to compare the operation of the virtual wing by gesture and force, three types of dynamic muscle contraction of the biceps brachii muscle are used as the myoelectric measurement positions: chest and shoulder.

2) Examination of presentation posotion: From Table 2, it was found that the evaluation was higher when the haptics presentation was made on the torso than on the extremities. Therefore, we investigate which part of the torso is the most effective for haptics presentation. It is known that the hand occupies a large proportion of the human sensory cortex, while the torso occupies a small proportion of the sensory cortex [7]. Accordingly, we thought that it would be better to classify the torso parts into large groups instead of small ones, so that we can investigate the differences in sensation between the parts. Consequently, we divided the torso into the upper and lower parts, and the front and back parts (chest, abdomen, back, and waist).

V. SUBJECT EXPERIMENT TO VERIFY THE DIFFERENCE BY POSITION

A. Purpose of the experiment

In the previous section, we confirmed that there is a difference in the sensation of flapping wings depending on the myoelectric measurement position and the haptics presentation position. In this section, we verify the difference in the sensation (degree of body image expansion) between the myoelectric measurement position and the haptics presentation position from the subject experiment.

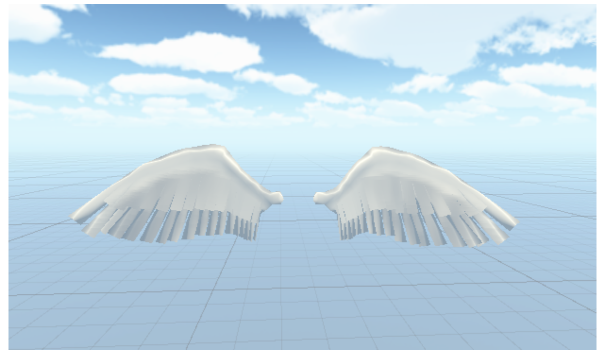


Fig. 9: Virtual Wings

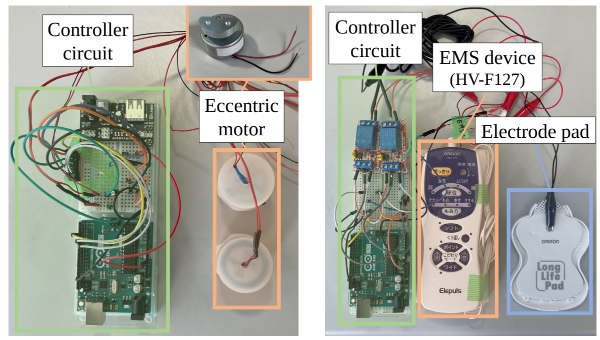


Fig. 10: Haptics display device (Left: Vibration, Right: EMS)

B. Expreimantal environment for conducting subject experiments

This section describes the experimental environment in which the subject experiment is conducted. In the subject experiment, as in the subjective evaluation experiment in Section 4, the experiment is conducted in a system with the environment as shown in Figure 4.

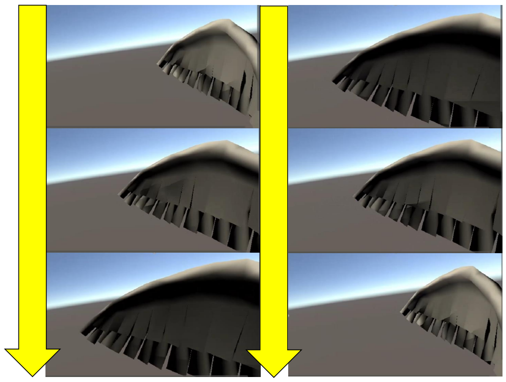
We use MyoWare (Fig. 5) as the myoelectric measurement devices. The acquired EMG values are sent to Unity to control the visual and haptics presentation devices.

The HMD (VIVE PRO EYE (HTC)) is used as the visual presentation device, and the virtual wings (Fig. 9) is presented from a first-person perspective.

Fig. 10 shows the haptics presentation devices. Fig. 10 left shows a device that controls an eccentric motor with Arduino to give vibration. Fig. 10 right shows a device that controls a low-frequency therapy device (Omron HV-F127) with Arduino and provides electrical stimulation.

In the VR space of this experiment, the gravitational acceleration g' is set to be equivalent to that of the moon to facilitate flight ($g' = 1.62$). It also gives an aerodynamic drag proportional to the speed during flight.

A specific flight method in VR space is described. First, the wings operation method is designed so that the virtual wings flaps inward while the operation position (electromyographic measurement position) is being applied, and the vir-



(a) Wings move inward (b) Wings move outward

Fig. 11: Movement of Virtual Wings

tual wings expands when it is relaxed (Fig. 11). By flapping the virtual wings, a force is generated in the direction of travel and ascent, allowning the aircraft to fly.

When the virtual wings are flapped inward, a haptics presentation is made. The intensity of the haptics presentation at this time according to the measured muscle potential.

C. Experimental method

Three types of myoelectric measurement positions, four types of haptics presentation positions, and two types of haptics presentation devices are compared. The myoelectric measurement positions are biceps brachii (dynamic contraction), pectoralis major (static contraction), and trapezius (static contraction), the haptics presentation positions are chest, abdomen, waist, and back, and the haptics presentation types are vibration and electricity.

The procedure of the experiment is shown below.

- The haptics sensation is presented by vibration. The myoelectric measurement position is fixed to the biceps brachii muscle (the part that is easiest to make a forceful movement), and the haptics presentation position is changed for comparison.
- The haptics sensation presentation position is fixed to the area with the highest evaluation, and the myoelectric measurement position is changed for comparison.
- Next, the haptics sensation is presented by EMS. The myoelectric measurement position is fixed to the area with the highest evaluation, and the haptics presentation position is changed for comparison.
- The position of the haptics sensation presentation was fixed to the area with the highest evaluation, and the myoelectric measurement position was changed for comparison.

The questionnaire was filled out using a 9-point Likert scale. The content of the questionnaire is shown below.

- Describe the evaluation of each of the haptics presentations (chest, abdomen, waist, and back).
- Describe the evaluation of each of the myoelectric measurement positions (arm, chest and shoulder).

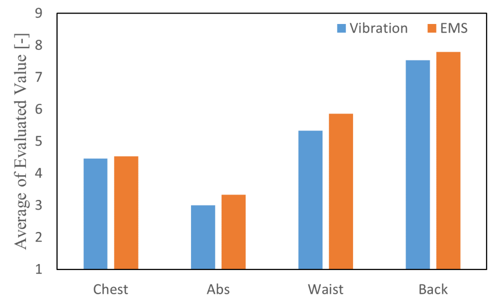


Fig. 12: Comparison of haptics display positions

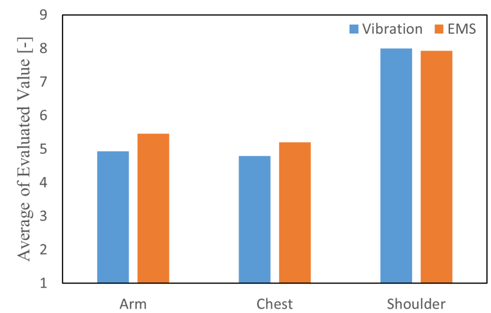


Fig. 13: Comparison of EMG measuring position

(Ask the above two questions twice, once using vibration and once using EMS as the haptics presentation.)

- Which haptics presentation gave you more of a sense of flapping wings and flying, vibration or EMS?
- Which did you feel was more important in presenting the sensation of flying with flapping, the myoelectric measurement position or the haptics presentation position?
- Were you able to feel the sensation of flying with flapping one's wings ?

D. Experimental results and discussion

Fig. 12 shows the mean values of the evaluation when the myoelectric measurement position is fixed and the haptics presentation position is compared. From the figure, it can be seen that the evaluation is high in the order of back, waist, chest, and abdomen regardless of whether the presenting device is vibration or electric stimulation. This indicates that the front and back of the torso have more influence on the evaluation of the body image expansion than the absolute distance from the virtual wing position given by the visual presentation.

Fig. 13 shows the average of the evaluations when the haptics presentation position is fixed and the myoelectric measurement position is compared. From the figure, it can be confirmed that the evaluation of the virtual wing manipulation by the shoulder is the highest regardless of whether the presenting device is vibration or electric stimulation. There was no significant difference between the evaluations of arms (dynamic muscle contraction) and chest (static muscle contraction), which are close to the position of the muscles.

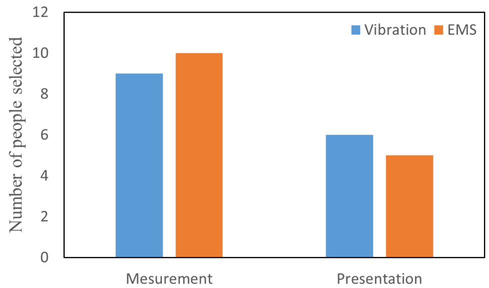


Fig. 14: Comparison of measuring position and haptics presentation position

This suggests that there is no significant difference in the sensations elicited by gestures (dynamic muscle contraction) and force (static muscle contraction) in body image expansion. In addition, the difference between the two gestures is small, even though the arm gesture is an intuitive action and the chest strain is an unusual and difficult action to perform. Therefore, it can be expected that the training of the manipulation by force will be more effective than the manipulation by gesture in enhancing the body image of the virtual wings.

Seven of the subjects answered that vibration was better for haptics presentation, and the remaining eight answered that electric stimulation was better. In addition to vibration, electrical stimulation is also useful for haptics presentation. Fig. 12 and Fig. 13 show that the evaluation of the presentation using the electric stimulus was higher in general. This can be attributed to the fact that the haptics sensation presentation using vibration stimulates the skin surface (superficial sensation), while the haptics sensation presentation using electrical stimulation easily transmits the stimulation to the muscles (deep sensation) in addition to the skin surface, thus increasing the mode of sensation presented.

Fig. 14 shows the results of the question whether the myoelectric measurement position or the haptics presentation position was more important in presenting the sensation of flapping wings independent of the limb. As shown in the figure, most of the subjects answered that the myoelectric measurement position was important in both cases of vibration and electric stimulation. The myoelectric measurement position is the part that acquires the information that works from the human while the haptics presentation position is the response from the wing. Therefore, it can be understood that the subjects place importance on the sense of moving the wings by themselves, and the sense of self-subjectivity. In the example of the RHI study, we mentioned that the spatial correspondence of the haptics presentation position is flexible in body image expansion. However, from the experimental results, it is considered that the spatial agreement of the

Finally, when asked if they could feel the sensation of flying with the wings sprouting from their backs, they were able to obtain an average rating of 7.11. Therefore, it was

myoelectric measurement position (manipulation position by force) is important in body image expansion.
found that the method proposed in this study can be used to extend the body image of virtual wings.

VI. CONCLUSION

In this paper, we focused on the study of giving the sensation of flying by moving the wings. We proposed a method of presenting the sensation of manipulating the wings without using the limbs and a method of transmitting the force acting on the wings to humans in VR space. We proposed a method of presenting the sensation of manipulating the wings without using the limbs, and a method of transmitting the force acting on the wings in the VR space to humans. From the subject experiments, it is considered that the factors of the front and rear surfaces of the body are more important than the absolute distance in presenting the haptics sensation. In addition, we proposed a method to evaluate the position of the myoelectric measurement by force. In addition, we showed that the evaluation was generally higher for the presentation using electric stimuli. Finally, we confirmed that the proposed method can be used to extend the body image of virtual wings.

In the future, we would like to increase the amount of information presented from the virtual wing to the human, and improve the equipment used in the experiments, such as changing the method of myoelectric measurement from single point measurement to multi-point measurement to obtain stable values. In this paper, the myoelectric measurement and haptics presentation positions were narrowed down to some extent for comparison, but by increasing the number of candidates, it will be possible to learn more about the differences by position.

REFERENCES

[1] K Carrie Armel and Vilayanur S Ramachandran. Projecting sensations to external objects: evidence from skin conductance response. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 270(1523):1499–1506, 2003.

[2] Mukul Bhalla and Dennis R Proffitt. Visual–motor recalibration in geographical slant perception. *Journal of experimental psychology: Human perception and performance*, 25(4):1076, 1999.

[3] Matthew Botvinick and Jonathan Cohen. Rubber hands 'feel'touch that eyes see. *Nature*, 391(6669):756–756, 1998.

[4] H Henrik Ehrsson. The experimental induction of out-of-body experiences. *Science*, 317(5841):1048–1048, 2007.

[5] Henry Head and Gordon Holmes. Sensory disturbances from cerebral lesions. *Brain*, 34(2-3):102–254, 1911.

[6] Atsushi Iriki, Michio Tanaka, and Yoshiaki Iwamura. Coding of modified body schema during tool use by macaque postcentral neurones. *Neuroreport*, 7(14):2325–2330, 1996.

[7] Wilder Penfield and Theodore Rasmussen. The cerebral cortex of man; a clinical study of localization of function. 1950.

[8] Max Rheiner. Birdly an attempt to fly. In *ACM SIGGRAPH 2014 Emerging Technologies*, pages 1–1. 2014.

[9] Howard G Thistle, Helen J Hislop, Mary Moffroid, and EW Lowman. Isokinetic contraction: a new concept of resistive exercise. *Archives of Physical Medicine and Rehabilitation*, 48(6):279–282, 1967.