Analysis and Evaluation of Behavior of R-V Dynamics Illusion in Various Conditions

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***Abstract*—This study examines the R-V Dynamics Illusion caused by different motion states of real and virtual objects. We discovered that various perceptual changes occur when a CG image imitating a liquid is superimposed onto a real object. The real object was perceived to be lighter when the real object was swung and the CG liquid moved, compared to when the liquid did not move, and the amount of muscle activity was found to decrease. In this research, the influence of the R-V Dynamics Illusion was analyzed by measuring the acceleration of the real object and the muscle fatigue of the subject. The experimental results showed that, when the real object was swung and the liquid moved, the object was swung at a low acceleration and the subjects' muscles tended to be fatigued.**

Keywords*—*Mixed Reality, R-V Dynamics Illusion, Multi-modal, Psychophysical Influence

I. INTRODUCTION

In recent years, virtual reality (VR) and mixed reality (MR) technologies have rapidly developed. Due to improvements in the performance of various sensors and authoring tools, they are utilized in various fields, including medicine, education, art, and entertainment. To enhance the reality of the experienced space, improvements must be made in haptic presentation technology and visual representation. For that reason, various haptic presentation devices have been developed, contributing to the construction of an immersive experience space [1][2]. However, haptic presentation using a device presents problems, such as limitations on the user's body and system complications.

To solve this problem, researchers have actively investigated multi-modal/cross-modal techniques, which reproduce haptics in a simple system by using the characteristics of humans' senses. One study reported an illusion called pseudo-haptics [3]. This is a phenomenon in which haptic sensation is perceived due to the difference between the actual movement of an object and the way it is represented visually. For example, haptic resistance is perceived when the movement of the pointer is decreased with respect to the movement of the mouse [4]. Thus, it is possible to reproduce various haptic sensations by changing only the visual representation of movement; physical stimulation is not necessary. Perceptions of, for instance, weight, hardness, and satiety, can be manipulated in this way [5-7]. It is important to clarify the influence, limitations, and mechanisms generated by the illusion for proper interface design.

Our research group has systematically analyzed the influence of pseudo-haptics using MR technology [8][9]. MR technology can seamlessly combine real and virtual space in real time, meaning that it is suitable for creating a situation in which the experience of touching an object and its appearance differ and for analyzing how humans perceive this difference. This research attempted to superimpose a computer-generated (CG) image imitating water on a rigid container. Changes in haptic sensation are perceived when the real object is swung and the liquid movement of the CG image is observed, even though the physical properties of the real object have not changed. We refer to the changes in haptic perception that occur when the real and virtual objects possess different motion states as Real-Virtual (R-V) Dynamics Illusion. We aim to elucidate the factors that influence the perception and mechanism of illusion [10].

Until now, illusion has been analyzed by subjective evaluation and electromyogram measurements [11]. We compared conditions in which the CG liquid moves and does not move when the real object is swung. Our results confirm that the real object was perceived to be light and the amount of muscle activity decreased when the liquid moved. Further, several subjects stated that they perceived the real object as easy to swing when they watched the liquid move. Previous studies have analyzed the influence of the illusion on perception, but not how a real object is swung [11]. Moreover, it is possible that muscle fatigue may also be affected if the movement of the real object changes depending on the visual information. Therefore, experiments were conducted to confirm the change in the acceleration of the real object and the influence of the subject's muscle

978-1-7281-1571-9/19/$31.00 ©2019 IEEE

fatigue. This paper reports the results of these experiments and the influences of the illusion.

II. RELATED WORK

Humans can perceive the weight, length, and shape of an object by holding or touching it. This is called dynamic touch [12]. Unlike when an object is passively touched, actively moving the object can reveal its characteristics [13]. However, humans recognize an object's information from multiple complementary senses. Therefore, the features of the object may be perceived differently depending on visual information. Pseudo-haptics is an illusion caused by human perception that is susceptible to visual influences [3]. It is thought that pseudo-haptics is caused by the influence of prior knowledge and everyday experiences. In other words, haptic information is supplemented by past experiences, even if the real object being touched is different than objects one has experienced. For example, Taima *et al.* reported that a real object was perceived as being lighter when the head mounted display (HMD) image was changed to lift higher when a real object was lifted [5]. This illusion is facilitated by past experiences in which light objects were lifted with ease. Changes in the perception of an object's hardness, satiety, and other characteristics can be explained by the same mechanism [6][7]. The R-V Dynamics Illusion causes perceptual changes by representing CG liquid inside a real object. This creates a type of pseudo-haptics caused by the experience of inertia that occurs when the liquid moves. There are many cases analyzing the perceptual characteristics of the pseudo-haptics, but few analyze changes in behavior caused. In this research focuses on the change of the acceleration of the real object and clarifies the influence on motion characteristics of R-V Dynamics Illusion.

The size-weight illusion that affects one's perception of the weight of an object due to the influence of visual information is related to the pseudo-haptics. The size-weight illusion is a phenomenon in which an object with a larger volume is perceived as lighter than another object with the same mass [14]. When an object is manipulated, the movement is constantly adjusted visually [15]. Verifying these findings regarding the size-weight illusion, several researches reported that as the volume of an object enlarges, it lifts more quickly and forcefully [16][17].

In addition, Kotani et al. [18] revealed that a white object (high brightness) is perceived as lighter compared to a black (low brightness) object. In this phenomenon, the low brightness object tends to be muscle fatigued [19]. Hence, the kinetic characteristics change due to changes in the visual information, even if the features of the object remain exactly the same. Similarly, in the R-V Dynamics Illusion, there is a possibility that the movement of a real object changes depending on the visual conditions, and that this may affect muscle fatigue.

III. OBJECTIVES AND PREPARATION

A. *Objectives*

This study analyzes the influence of changes in the movement of a real object and subject's muscle fatigue when a CG image imitating water is superimposed onto a real object. Three experiments were conducted in this study. The preliminary experiment reevaluated the influence of R-V Dynamics Illusion on subjective perception. Experiment 1 analyzed the influence of the illusion by measuring the acceleration of the real object and the amount of muscle activity. Experiment 2 analyzed the influence of the R-V Dynamics Illusion on muscle fatigue.

B. *Preparations*

Experiment environment

The system configuration used during the experiments is shown in Fig. 1. A video see-through HMD (Canon, HM-A1) and MR space management software (Canon, MREAL) were used for the MR system. To superimpose the CG image onto the real object, the position and orientation of the subject's head and the real object were acquired with a magnetic sensor (Polhemus, 3 SPACE FASTRAK).

An occlusion problem occurred in the subject's arm when the real object was grasped and the CG image was superimposed onto it. Hand region extraction and masking were performed based on the image captured by the HMD in order to superimpose the CG image onto the object in the correct position. The experiments were conducted in an environment with an HMD resolution of 1280 × 960 pixels and a frame rate of 30 FPS. In addition, it was confirmed that there was no discomfort concerning the time delay or positional relationship before the experiment.

Real object

An acrylic container with a dimension of 165 mm × 90 mm × 80 mm (width × height × depth) was prepared, and a handle was attached at the top. The weights were then fixed inside the container so they would not move (Fig. 2). The mass of the real object was 750 g. The mass was adjusted to reflect the weight of the object if water were filled to 45 mm, half the height of the container. The subject swung the real object by gripping its handle.

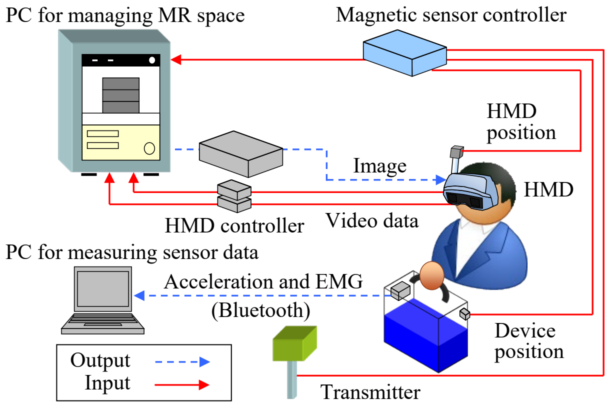


Fig. 1. System configuration for constructing the MR space

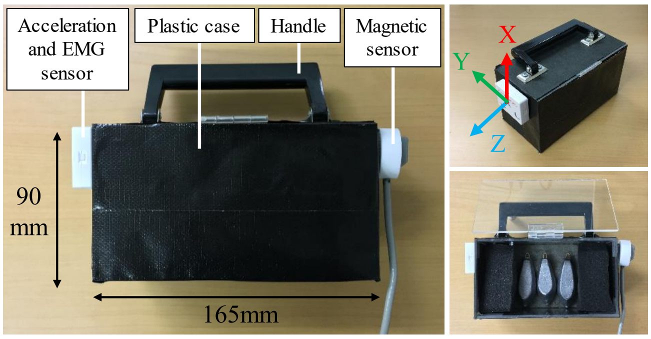
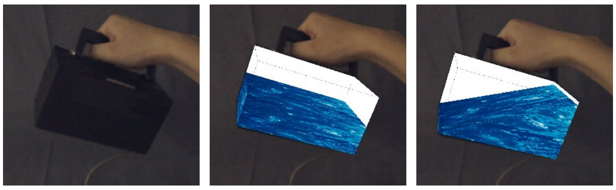


Fig. 2. Real object used in the experiments



(a) No CG (b) Not Moving (c) Moving

Fig. 3. Virtual object used in the experiments

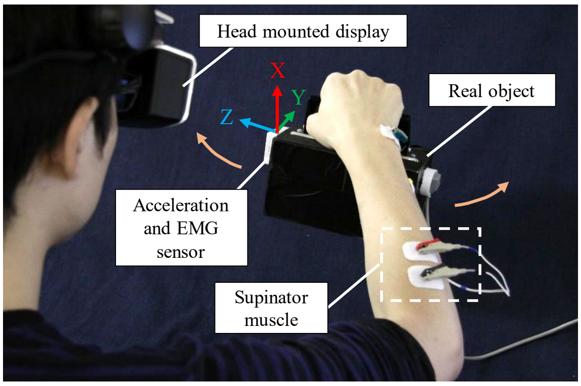


Fig. 4. Experimental scene

Virtual object

A virtual container with a dimension of 165 mm × 90 mm × 80 mm (width × height × depth)—the same size as the real object—was superimposed onto the real object. The CG image of liquid was superimposed at a height of 45 mm height inside the virtual container. The liquid in the CG image was colored blue, and the inner wall of the virtual container was colored white (Fig. 3). In the experiment, the following three visual conditions were used:

- No CG: A CG image was not superimposed onto the real object (Fig. 3 (a)).
- Not Moving: The superimposed CG image of liquid did not move, even if the real object was tilted (Fig. 3 (b)).
- Moving: The superimposed CG image of liquid moved when the real object was tilted (Fig. 3 (c)).

Since the No CG condition did not superimpose CG image onto the real object, the visual brightness is lower than the other two conditions. The swinging of the real object was unified in a left–right direction. The liquid in the CG image was represented by a simple model in which the surface of the liquid moves to the left and right without splashing or creating a wave. The study confirms that the real object seems to contain water (please refer to the previous research on detailed liquid model algorithms [11]). The subject performed the experiments in environments in which the real object, the CG image, and their own arms were the only things in sight (Fig. 4).

Measurement of acceleration and surface electromyogram

In the experiments, the acceleration of the three axes of the real object and the surface electromyogram (EMG) of the subject were measured using a small wireless sensor (ATR-Promotions, TSND-121). The sensor was attached to the left side of the object, and disposable electrodes were attached to the supinator muscle of the subject's forearm (Figs. 2 and 4). The electrodes were placed 25 mm apart, and the earth electrode was placed at the styloid process of the ulna after sebum was removed with alcohol in order to reduce skin resistance. The measured analog signal was transmitted to the computer via Bluetooth at a sampling frequency of 500 Hz.

IV. PRELIMINARY EXPERIMENT: REEVALUATION OF THE INFLUENCE OF THE R-V DYNAMICS ILLUSION ON PERCEPTION

A. Objective

In the preliminary experiment, the influence of the R-V Dynamics Illusion on subjective perception was reevaluated. Although it was confirmed that the illusion influenced the subject's perception of the weight of the object, several subjects stated that they perceived real object different maneuverability depending on condition. Hence, the influence of subjective maneuverability was evaluated before the changing movement of the real object was analyzed.

B. Condition and Evaluation Method

The fact that the R-V Dynamics Illusion affects weight perception was confirmed by Thurston's pairwise comparison method [11]. However, this method forces one to choose between two choices, even if the comparison conditions are ambiguous [20], and therefore it is possible that statistical differences can be confirmed even when comparisons show no difference. Thus, this study adopted Scheffe's method, which allows for intermediate answers when subjects do not feel a difference, and examined the influence of weight in addition to maneuverability [21].

The three conditions listed in Section 3.B—No CG, Not Moving, and Moving—were compared in the preliminary experiment (Figs. 3a–3c). Two conditions were chosen, and the subject was asked to identify the condition in which they perceived the object as being lighter or easier to swing (Ura's variation) based on Scheffe's pairwise comparison method. This comparison was repeated for all conditions, and the psychological scale of each condition was calculated. Scheffe's method is compared in the following five stages in this experiment:

- The former is light/easy to swing (-2)
- If anything, the former is light/easy to swing (-1)
- Same weight/maneuverability (0)
- If anything, the latter is light/easy to swing (+1)
- The latter is light/easy to swing (+2)

The subject was instructed to swing the real object in a left–right direction at a 30-degree angle. The subject stood erect and flexed the elbow at 90 degrees. The real object was swung five times in accordance with a metronome (70 beats per minute) for each condition.

If trials were continuously carried out in the experiment, arm fatigue may have affected the results. Therefore, the subjects took a break when they felt tired. Further, weight and maneuverability were not evaluated at the same time, and experiments were conducted separately.

C. Procedure

The specific experimental procedures are as follows:

(i) The HMD was attached to the subject.

(ii) Two conditions were randomly selected from the three conditions.

(iii) One condition was randomly selected from the two conditions selected in (ii) and presented to the subject.

(iv) The real object was swung to the left and right (70 bpm, five complete swings).

(v) The object was swung the same way in the other condition selected in (ii).

(vi) The two conditions were compared and the subject identified the one in which the object felt lighter.

(vii) The subject took a break to eliminate muscle fatigue.

(viii) Steps (ii)–(vii) were repeated for the remaining combinations.

(ix) Maneuverability was evaluated in the same manner as in steps (i)–(viii).

The subjects were 10 right-handed men in their 20s. The trials were performed 12 times for each subject, and the total number of trials was $_3P_2 \times 2$ (combination of conditions × number of evaluations).

D. *Results and Discussion*

The results of the preliminary experiment are shown in Fig. 5. The number line in the figure shows the psychological scale of the weight and maneuverability in each visual condition. Small numerical values indicate that the real object is perceived as heavy/difficult to swing, and large numerical values indicate that the object is perceived as light/easy to swing.

The analysis of variance on weight perception confirmed a significant difference in the main effect of the visual conditions ($F(2, 18) = 27.67$, $p < 0.01$). Significant differences were found among all the conditions ($p < 0.05$) in multiple comparisons based on the confidence intervals. There were no significant differences between the effect of order and combination. Of the three conditions, the object was perceived as heaviest in the No CG condition. The previous study has reported that real object with lower brightness was perceived more heavily [18]. There were differences in visual brightness between the No CG condition and the other two conditions. Therefore, it is thought that the visual brightness of the real object has influenced weight perception. The object was perceived as lighter in the Moving condition compared to the Not Moving condition. In order to feel the real object lightly, it is necessary to swing while watching the movement of the liquid. The difference in perceived weight was confirmed using Scheffe's method in addition to Thurstone's method [11].

The variance analysis of maneuverability confirmed a significant difference in the main effect of the visual condition ($F(2, 18) = 26.99$, $p < .01$). Multiple comparisons revealed no significant difference between the No CG and Not Moving conditions. However, other combinations were found to have significant differences ($p < 0.01$). In addition, there were no significant differences in order and combination effect. The Not Moving and Moving conditions both feature superimposed CG images of liquid, differing only in the movement of the liquid. The experimental results show that swinging the real object while watching the movement of the liquid led subjects to perceive the object as being easy to swing. In addition, there was no significant difference between the No CG condition, in which the subject swung a black object, and the Not Moving condition, in which the subject swung the object and the liquid did not move. Both conditions are the same in that the visual dynamics do not change. Therefore, no difference in maneuverability was found.

V. EXPERIMENT 1: ANALYSIS OF THE INFLUENCE OF THE R-V DYNAMICS ILLUSION ON THE MOVEMENT OF REAL OBJECT

A. *Objective*

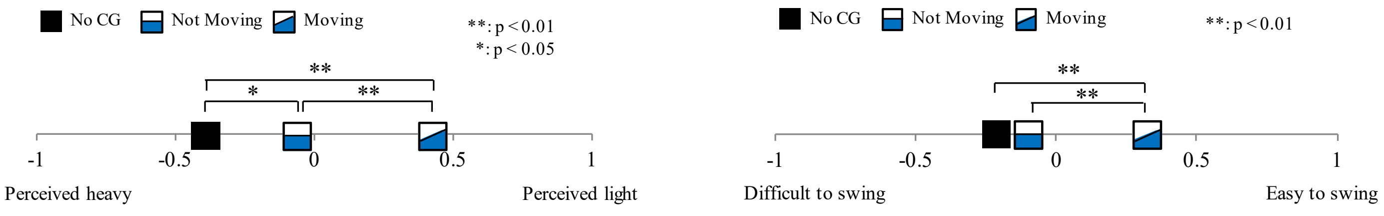
The preliminary experiment confirmed that the real object was perceived to be light and easy to swing when the liquid moved. If the subject's perception changes according to the appearance of the object, it is possible that a difference may be observed in the swinging motion of the real object. Therefore, in Experiment 1, we analyzed the influence of the swinging motion and the mechanism of the illusion by measuring the acceleration of the real object and the muscle activity of the subject.

B. *Condition and Evaluation Method*

The acceleration of the real object and the muscle activity of the subject were measured for each condition examined in the preliminary experiment. Acceleration was evaluated by analyzing the value of the acceleration sensor attached to the real object for each visual condition. The measured acceleration was processed using a low-pass filter with a cutoff frequency of 20 Hz after eliminating the influence of the gravitational component. The mean absolute value and resultant acceleration of the x-axis and z-axis in the direction of the swing motion were calculated. The resultant acceleration Acc_{xz} of swinging time T was calculated using Formula (1).

$$Acc_{xz} = \frac{1}{T}\sum_{t=1}^{T}\sqrt{A_x(t)^2 + A_z(t)^2} \qquad (1)$$

Muscle activity was evaluated by measuring the supinator muscle of the forearm. The percentage of maximal voluntary contraction (%MVC), representing the force of the



(a) Perceived weight

(b) Maneuverability

Fig. 5. The results of the preliminary experiment (i.e., influence of the conditions on perceived weight and maneuverability)

muscle, was calculated from the amplitude information of the surface electromyogram and used as an index. The %MVC shows the myoelectric potential ratio of the electromyogram to the MVC of maximum muscular force, which was calculated as shown in Formula (2). The MVC of each subject was measured before the experiment.

$$\%MVC = \frac{1}{T}\sum_{t=1}^{T} \frac{EMG(t)}{MVC} \times 100 \qquad (2)$$

Signal noise was removed from the measured surface electromyogram with a high-pass filter with a cutoff frequency of 20 Hz and a hum filter with a frequency of 60 Hz. Then, the waveform was rectified and smoothed with a 5 Hz low-pass filter. Conditions such as the method of swinging, rhythm, and posture remained the same as in the preliminary experiment.

C. Procedure

The specific experimental procedures are as follows:

(i) The HMD was attached to the subject.

(ii) One condition was randomly selected from the three conditions and presented to the subject.

(iii) The real object was swung to the left and right (70 bpm, five complete swings).

(iv) The real object was kept stationary for the same length of time as in step (iii).

(v) Steps (iii) and (iv) were repeated three times.

(vi) The subject took a break to avoid muscle fatigue.

(vii) Steps (ii)–(vi) were repeated for the remaining conditions.

The subjects were seven right-handed men in their 20s, and the trials were conducted three times per subject.

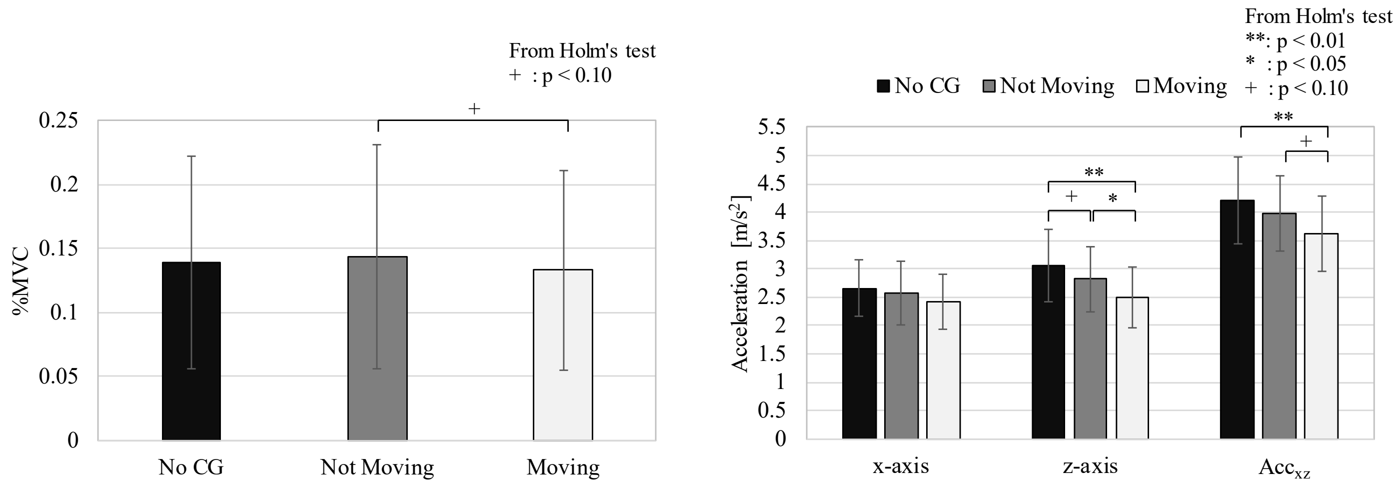
D. Results and Discussion

The results of Experiment 1 are shown in Figs. 6. Fig. 6 (a) shows the average %MVC, with higher numerical values indicating greater muscular force. Fig. 6 (b) shows the average acceleration of the real object, calculated from the section in which the subject swung the real object. The representative value is the average value measured in three sections for each visual condition. The error bars represent standard deviations.

The analyses of variance on the muscle activity shown in Fig. 6 (a) revealed a marginally significant ($F(2, 18) = 2.94$, $p < 0.1$). In addition, Holm's multiple comparisons showed a marginally significant between the Not Moving and Moving conditions ($p < 0.1$). These results confirmed that, in the Moving condition, subjects swung the real object with little muscle activity. There were no significant differences between the No CG condition and the other conditions. These trends in results were identical to those found in a previous study [11].

The analyses of variance on the acceleration shown in Fig. 6 (b) reveal significant differences in the average absolute value of the z-axis and resultant acceleration (z-axis: $F(2, 18) = 10.55$, $p < 0.01$, Acc_{xz}: $F(2, 18) = 8.18$, $p < 0.01$). Holm's multiple comparisons showed significant differences for resultant acceleration except between the No CG condition and the Not Moving condition. The above results reveal a tendency towards different accelerations, even when the angle and rhythm at which the object was swung was controlled. There was no significant difference between the visual conditions on the x-axis, but there was a significant difference on the z-axis. Therefore, the movement of the real object varies in the horizontal direction rather than the vertical direction, depending on the visual conditions. The typical tendencies regarding the acceleration and %MVC waveforms of the subject are described in the appendix.

Significant differences were found in resultant acceleration, excluding the No CG and Not Moving conditions. This is the same trend as found for maneuverability in the preliminary experiment. Although the Not Moving condition features a superimposed CG image imitating liquid, the liquid does not move even if the real object is swung. It can be said that it is simply a condition in which subjects swings a real object on which a pattern of liquid is drawn. Thereby, no significant difference was observed in the acceleration evaluation or subjective evaluation of maneuverability due to the visual dynamics of the No CG condition and the Not Moving condition are same. In the Moving condition, the CG liquid moved based on the swing of the real object. The swing motion was smooth compared with the other conditions as the movement of the liquid was controlled.



(a) %MVC

(b) Acceleration

Fig. 6. The results of Experiment 1 (i.e., the influence of the conditions on subjects' %MVC and the acceleration of the real object)

VI. EXPERIMENT 2: ANALYSIS OF THE INFLUENCE OF THE R-V DYNAMICS ILLUSION ON MUSCLE FATIGUE

A. Objective

Experiment 1 confirmed that the real object was swung with little acceleration and muscle activity in the Moving condition compared to the Not Moving condition. This indicates that if the swinging motion of the real object differs based on visual conditions, muscle fatigue may be altered. Therefore, in Experiment 2, we analyzed the influence of visual movement of the CG liquid on muscle fatigue.

B. Condition and Evaluation Method

Muscle fatigue was evaluated by swing the object for 60 seconds under each condition. When investigating the influence of muscle fatigue, Ban *et al.* reported that a black object caused more muscle fatigue than a white object [19]. Hence, the No CG condition, in which the object appeared black, was expected to show the highest muscle fatigue and was excluded from the experiment. The subjects were examined under both conditions in a single day. Another trial was conducted on another day in which the order of the conditions was changed. Breaks were set to 40 minutes or more so that muscle recovery could be confirmed. The other conditions are identical to those in Experiment 1.

To evaluate muscle fatigue, the mean frequency (MEPF) and the median frequency (MDPF) of the power spectrum was determined by processing a fast Fourier transformation on the surface electromyogram. MEPF and MDPF were calculated according to Formulas (3) and (4), and these values decreased with muscle fatigue [22].

$$MEPF = \frac{\int_0^\infty f * p(f)df}{\int_0^\infty p(f)df} \tag{3}$$

$$\int_0^{MDPF} p(f)df = \int_{MDPF}^{\infty} p(f)df \tag{4}$$

The signal filtering process was identical to that used in Experiment 1, and the analysis range of the power spectrum was from 20–250 Hz.

C. Procedure

The specific experimental procedures are as follows:

(i) The HMD was attached to the subject.

(ii) One condition was randomly selected from the two conditions and presented to the subject.

(iii) The real object was swung to the left and right (70 bpm, 60 seconds).

(iv) The subjects took a break for more than 40 minutes to avoid muscle fatigue.

(v) Step (iii) was performed under the other conditions.

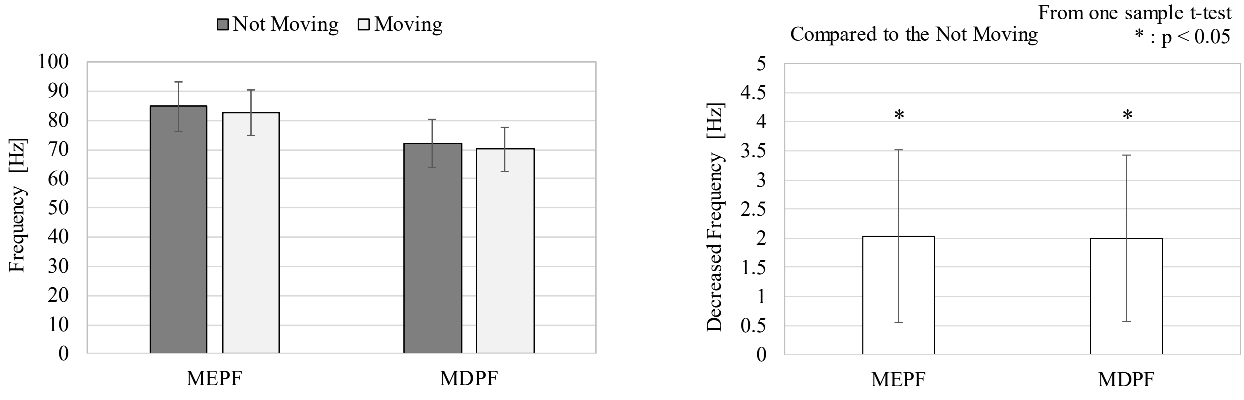
(vi) The order of the conditions was changed and steps (i)–(v) were performed again at intervals of one day or more.

The subjects were eight right-handed men in their 20s. The trials were conducted four times per subject and the total number of trials was 2 × 2 (conditions × order).

D. Results and Discussion

The results of Experiment 2 are shown in Figs. 7. Fig 7 (a) shows the average values of MEPF and MDPF, with lower numerical values indicating greater muscle fatigue. In addition, Fig. 7 (b) shows the average decreased values of MEPF and MDPF of Moving condition compared to Not Moving condition. Higher numerical values indicate that the Moving condition is more muscle fatigue than Not Moving condition. The representative value is the average value measured twice for each visual condition. The error bars represent standard deviations (Fig. 7 (a)) and 95% confidence interval (Fig. 7 (b)). According to the one sample t-test of influence, muscle fatigue was caused by movement of the liquid, and significant differences in both MEPF and MDPF were confirmed (MEPF: $t(7) = 2.69$, $p < 0.05$, MDPF: $t(7) = 2.75$, $p < 0.05$).

Experiment 1 showed the tendency for acceleration and muscle activity to be lower in the Moving condition than in the Not Moving condition. Therefore, it was expected that the Not Moving condition caused more muscle fatigue than the Moving condition. However, different results were obtained than expected. This may be related to human feedforward control, a model that predicts the next move from the current state, and it can be seen with rapid motion. In feedforward control, the movement-related cortical potential is observed prior to movement [23]. This is the brain potential that is observed in advance before trying to move the body. The opposite theory is feedback control, in which errors are corrected in motion and can be seen with dull motion. In this experiment, in which a real object is swung left and right quickly, it is conceivable that the subject



(a) Muscle frequency (b) Decreased muscle frequency

Fig. 7. The results of Experiment 2 (i.e., the influence of the conditions on subjects' muscle fatigue)

achieved motion mainly by using feedforward control.

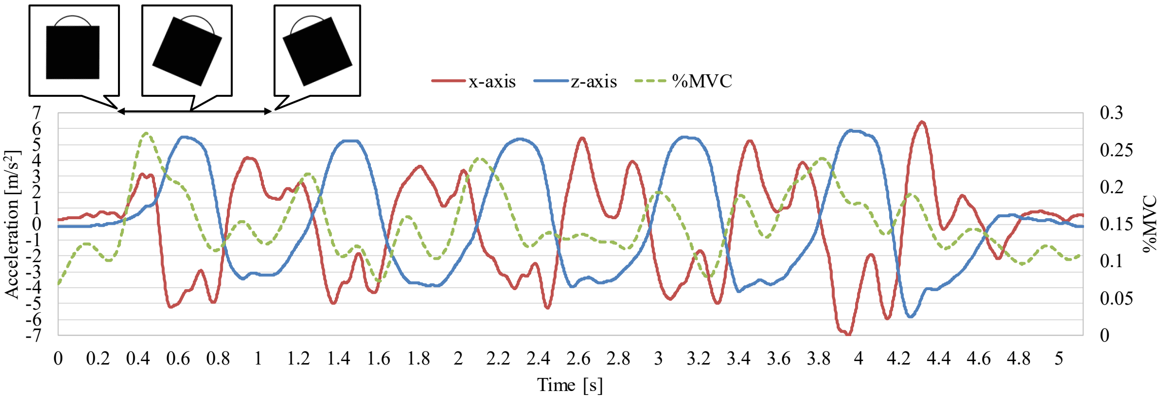
In the Moving condition, subjects had to repeat the motion while predicting and controlling the movement of the liquid, unlike in the Not Moving condition. Therefore, feedforward control is stronger in the Moving condition than in the Not Moving condition. Yoshida *et al.* reported that before the human acts something, the movement-related cortical potential and muscle activity are observed [24]. Moreover, Slobounov *et al.* reported that movement-related cortical potential is significant if the intention to cause motion is strong [25]. Based on this, muscle tone increased because subjects were more aware of their motion in the Moving condition compared to the Not Moving condition. As a result, there were differences in the influence of muscle fatigue.

VII. CONCLUSIONS

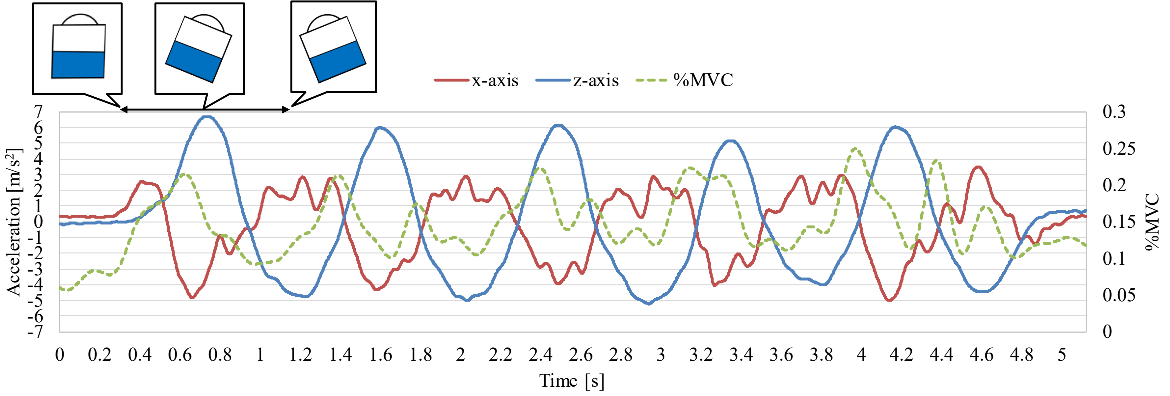
This research focused on the R-V Dynamics Illusion caused by differences in motion between real and virtual objects. It analyzed the influence of a CG image imitating liquid superimposed onto a real object on swing motion and muscle fatigue. The experiments revealed three findings when subjects swung the real object while watching the liquid move, compared to the condition in which the liquid did not move:

- Subjects perceive the real object as light and swingable (as shown in the preliminary experiments).
- The acceleration in the left–right direction (z-axis) when swinging the real object is low, as is the amount of muscle activity (as shown in Experiment 1).
- Muscle fatigue is high (as shown in Experiment 2).

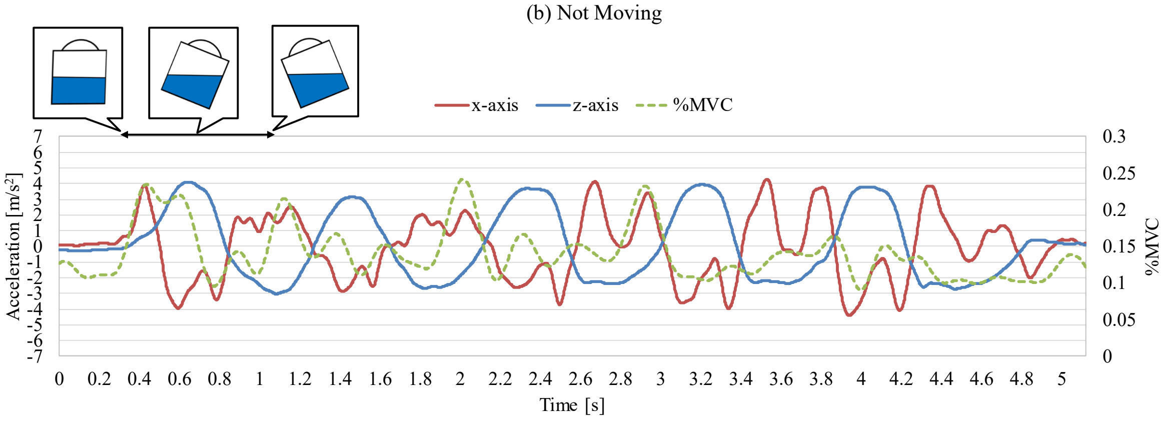
It was confirmed that swinging the real object while watching the liquid move influenced subjects' perception and swing motion. Besides, it was suggested that R-V Dynamics Illusion and feedforward control have a relationship, because of the movement of the CG liquid influence on muscle fatigue.



(a) No CG



(b) Not Moving



(c) Moving

Fig. A. The results of Experiment 1 (i.e., the typical tendencies regarding subject's %MVC and acceleration waveforms)

This study focused on conditions that confirmed the occurrence of illusions in the previous study based on several parameters. However, the mass and method by which the real object is grasped can also be considered parameters that affect the illusion. In addition, there is a possibility that the gender differences of the subject also affect the illusion. From now on, we will systematically analyze the influence of various conditions on the perceptual characteristics of the illusion and the motion characteristics of the real object.

APPENDIX: TYPICAL SUBJECT'S WAVEFORM OF ACCELERATION AND %MVC

Experiment 1 revealed that acceleration and muscle activity vary depending on the visual conditions. In particular, there was a difference in the z-axis acceleration. The typical tendencies regarding the subject's acceleration and %MVC waveforms during five complete swings are presented in Fig. A.

ACKNOWLEDGMENT

This work was supported in part by a Grant-in-Aid for Scientific Research (A), Grant Number 17H00754, and Scientific Research (B), Grant Number 16H02861.

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