R-V Dynamics Illusion: Psychophysical Influence on Sense of Weight by Mixed-Reality Visual Stimulation of Moving Objects

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Abstract. When humans sense the weight of real objects, their perception is known to be influenced by not only tactile information but also visual information. In a Mixed-Reality (MR) environment, the appearance of touchable objects can be changed by superimposing a computer-generated image (CGI) onto them (MR visual stimulation). In this paper, we studied the psychophysical influence on the sense of weight by using a real object that has a CGI superimposed on it. In the experiments, we show CGI representing the inertial force caused by the movable objects inside, while the subject swings the real object. The results of the experiments show that the subjects sensed weight differently when being shown the CGI animation.

Keywords: Mixed Reality, Sense of Weight, Visual Stimulation, Psychophysical Influence.

1 Introduction

Using mixed reality (MR) technology, real and virtual worlds can be merged [1][2]. In an MR environment, the visual information of the virtual object can be superimposed on a real object with no change in tactual sense. In other words, users have the tactile feeling of the real object while viewing the superimposed digital data [3]. This implies that material and/or shape of the object can differ between visual and tactual sense. In such a situation, what kind of psychophysical phenomenon could be occurring? Based on this question, we have systematically performed various experiments to investigate this influence of “MR visual stimulation” on tactile sense and have found various illusions. For example, we had indicated that when objects with different degrees of virtual roughness are presented to both visual and tactile senses and the tactile stimulus are over a certain threshold of roughness, the subjects perceive the objects to be tactually different although the objects have no physical difference [4][5]. This implies that the tactile impression can be intentionally changed by providing the appropriate visual stimulation. We also confirmed that when a subject pushes the real object on which the virtual object that deforms differently from the real object is superimposed, he/she perceived the object as being harder or softer than the real

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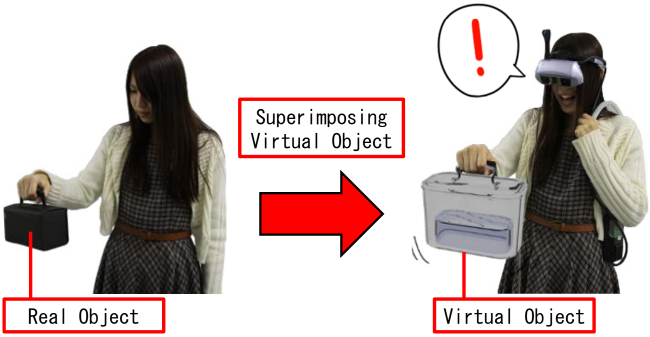

Fig. 1. R-V Dynamics Illusion

object. We found that, in some cases, visual stimulation had a significantly larger effect than the actual hardness of the real object [6][7].

Additionally, we focused on the center of gravity (COG) and examined the influence of superimposing virtual objects having different COG positions onto real objects. As a result, we confirmed that COG perception can be influenced by superimposing virtual objects, and we named this illusion the "Shape-COG Illusion [8]." In the experiments of "Shape-COG Illusion," we only focused on the rigid object for both real and virtual stimulation whose COG position is clear for the subjects. However, through the experiments, new question has raised. That is, if real and/or virtual objects are non-rigid (deformable or having movable portion in it), how are they perceived?

In this study, we firstly focus on a situation in which a virtual object that has movable portion in it is superimposed on a real rigid object (Fig. 1). This paper describes the experiments we conducted to analyze the influence.

2 Related Work

"Dynamic Touch" is a haptic perception with motion [9][10]. With this perception, a person can sense and recognize the information, such as the size, shape, and weight, of a holding object without looking at it by swinging it. Even if the object is deformable or has movable portion in it, he/she can recognize its movement roughly. In this paper, we focus the case that this deformation or internal movement differs between visual and tactual sense.

"Pseudo-Haptics [11-14]" and "Size-Weight Illusion [15]" is known as illusions occurred by interaction between visual and tactual sense. "Pseudo-Haptics" is an illusion in which a person can perceive tactual sense, such as softness, texture, and viscosity of an object, only by controlling visual stimulation. This phenomenon could be closely-related to our study on the point that both changes tactual sense only by changing visual sense (with no use of haptic display).

"Size-Weight Illusion" is a well-known and typical illusion of weight [15][16]. When grasping objects of the same weight but different sizes, a person perceives the bigger object to be lighter than the smaller one. Moreover, Roch et al. confirmed that when a cube in a subject's hand appears larger through a magnifying glass, he/she perceives it as being lighter than actual [17]. In these studies show that perception of mass can be influenced by visual stimulation. However, internal movement of an object is not considered in these studies.

There are some studies about the influence of MR visual stimulation on haptic perception, including our previous studies [4-8]. Kitahara et al. confirmed that visual stimulation in an MR environment affects the haptic perception of texture and sharpness of an edge [18]; this idea is similar to [4]. Nakahara et al. described the result of experiments on the curvature factor of edges [19]. However, these studies examined only the haptic sense of the material and/or haptic exploration of the object's shape [20]. Ban et al. report that the color of superimposing objects affects weight perception [21]. However, a study which addresses the case having different internal movement between visual and tactual sense has yet been conducted.

3 Purpose and Preparation of Our Study

3.1 Purpose of Our Study

We conducted experiments to verify the influence of dynamic change of MR visual stimulation on the tactile sensation. There could be many kind of combinations of experiments, for example, a case that a real object is rigid and a virtual object is dynamically changeable, a case that both of them are dynamically changeable, a case that movable objects are solids, a case that movable object is liquid, and so on. Therefore, in this paper, we start from a condition in which a real object is rigid case with handle and as MR visual stimulation it is superimposed by the same size virtual case filled with liquid.

In the experiment 1, we superimpose MR visual stimulation on real rigid object, which is reminded of moving liquid in an object to confirm whether tactual perception is different between a case that liquid in the object moves according to the user's hand movement and a case that liquid dose not move. In experiment 2, we verify the influence of virtual liquid level in the virtual object.

3.2 Experimental Environment

In the following experiments, we adopted an MR system with a video see-through mechanism that visually merges the real and virtual worlds (Fig. 2). Wearing a head-mounted display (HMD) (VH-2002, Canon Inc.) with a pair of built-in video cameras, the subject viewed the stereoscopic images that are computer-generated images (CGIs) in the scene in front of his/her eyes. In other words, the subject saw the CGIs that were texture-mapped onto the objects with high geometric precision. Head position and position of real object was constantly tracked with six degrees of freedom (6-DOF) by a magnetic sensor (3SPACE FASTRAK, Polhemus Inc.), which allows the subject to move his/her head freely.

3.3 Preparation of Experiments

The real rigid object used in the experiments was a plastic case (165 mm width × 90 mm height × 80 mm depth) with the handle (Fig. 3). The weight of the plastic case was adjusted to 750 g, which was the weight of a case filled with water up to the level of 45 mm (50 % of the case height).The size of virtual object used as MR visual stimulation was the same as the real object. In the virtual object, water colored virtual liquid was filled. We prepared five liquid levels, CG1 27mm (30% of the virtual object's height), CG2 36mm (40%), CG3 45mm (50%), CG4 54mm (60%), and CG5 63mm (70%) for the experiments (Fig. 4). Table 1 shows patterns of MR visual stimulation used in the experiments. There were ten patterns of CGI which is the combination of liquid level and liquid motion (moving/not moving).

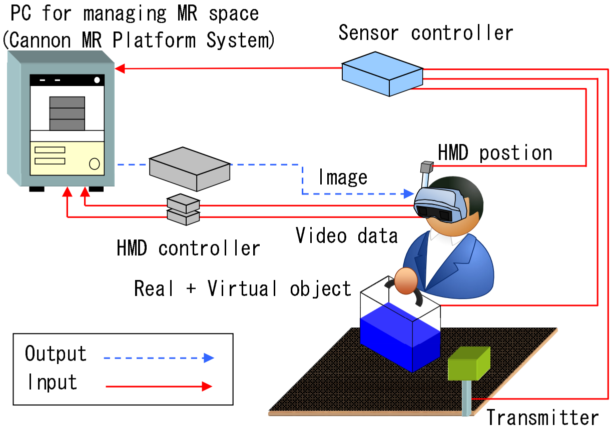

Fig. 2. System Configuration

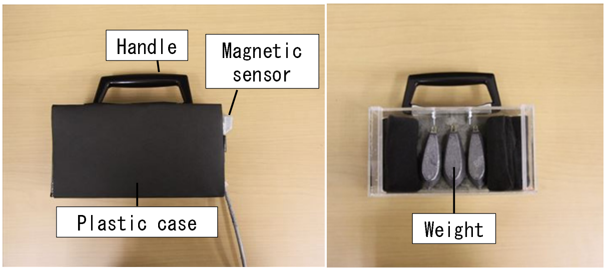

Fig. 3. Real Object Used in Experiments

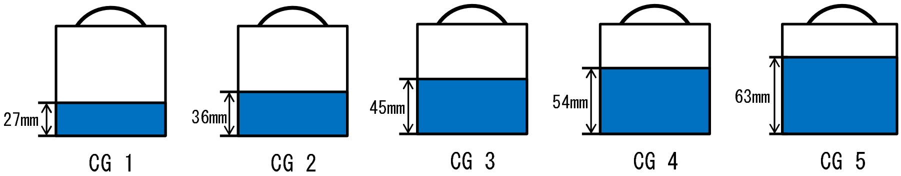

Fig. 4. Virtual Stimulation Used in Experiments

3.4 Evaluation Methods

In the experiments, we used Thurstone's paired comparison method for the subjective evaluation. This method is a simple psychological measure and can prevent confusion due to the large number of choices. The objective response was measured by electromyography (EMG). To measure electromyographic signals during the experiment, we attached disposable electrodes to the subjects' forearm (Fig. 5). The measurement of EMG uses surface electromyography meter (ATR-Promotions, TS-EMG01). If the force is affected by the MR visual stimulation, then the difference should be observed in the EMG. Therefore, we measured the objective response to this illusion by the EMG. In the experiments, a subject swings the plastic case to the right and left. Since this motion is a pronation-supination movement, we put a electrodes on a supinator muscle. The distance between electrodes was set at 25 mm. We put a ground electrode on the olecranon. The analog signal was derived from the surface EMG meter and the sampling frequency was 500 Hz.

Table 1. Variety of MR Visual Stimulation Used in Experiments

Pattern	Motion	Levels
1	Moving	27 mm (CG1)
2		36 mm (CG2)
3		45 mm (CG3)
4		54 mm (CG4)
5		63 mm (CG5)
6	Not moving	27 mm (CG1)
7		36 mm (CG2)
8		45 mm (CG3)
9		54 mm (CG4)
10		63 mm (CG5)

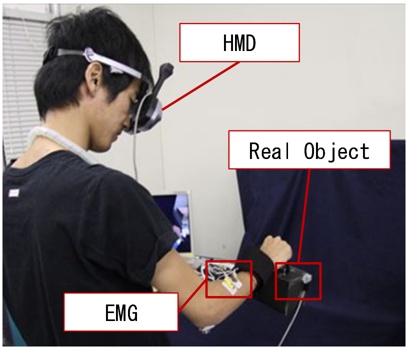

Fig. 5. Experimental Scene

In order to evaluate the muscle activity in the supinator in the swinging operation, we used the %MVC (Maximal Voluntary Contraction) index of the degree of activity of the muscle, which is calculated from the amplitude information [22]. After the full-wave rectified waveform was obtained from EMG and the normal MVC was measured for each subject, the %MVC was calculated.

4 Experiment 1

4.1 Purpose

In experiment 1, we superimpose MR visual stimulation on real rigid object, which is reminded of moving liquid in an object to confirm whether tactual perception is different or not between two patterns; pattern 3 and 8 in Table 1. In pattern 3, a CGI of liquid was shown moving inside the cases according to the swinging of the case. In pattern 8, the liquid CGI was not moving.

4.2 Experimental Procedure

The liquid level of superimposed CGI was 45 mm (pattern 3 and 8 in Table 1). The subjects were five men. The experimental procedure is described below:

1. The subjects wear the HMD and electrodes are attached on their forearms.
2. Either pattern 3 (liquid is moving) or 8 (not moving) was superimposed onto the same real rigid object presented to subjects' HMD. Patterns are selected randomly with each subject.
3. The subjects asked to bend their elbows about 90 degrees and hold the real object and swing them right and left according to a metronome (100 strokes/min).
4. The subject rests for 3 sec and repeat steps (3) to (4) three times.
5. Sufficient breaks are provided to eliminate the effect of muscle fatigue.
6. For the other pattern (a pattern not selected at step (2)), steps (3) to (5) are repeated.
7. After the experiment, the subjects asked to report any difference in the tactual sensation in each trial.

4.3 Results and Discussion

When the liquid CGI is shown to be moving, all subjects felt the object to be lighter than the case where the liquid is not moving, according to the interviews conducted at the end of the experiment.

Fig. 6 shows the results of calculating the average of the %MVC supinator in the interval. The period of analysis was 3 sec from the start to the end of the swinging motion. The figure shows that, by presenting MR visual stimulation in which a CGI of liquid is shown to be moving, the muscle activity of the supinator was reduced. A t-test showed significant differences in the %MVC of supinator motion between the patterns ($p < 0.01$).

From these results, it appeared that the MR visual stimulation having movable portion could affect the sense of weight.

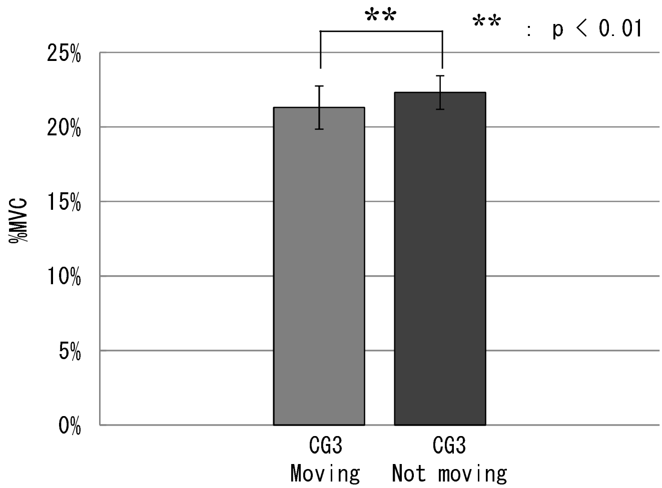

Fig. 6. Results of Experiment 1 (Average %MVC)

We named this psychophysical influence caused by the difference between dynamics of the real object (R) and the virtual object (V) movement, the “R-V Dynamics Illusion.”

5 Experiment 2

5.1 Purposes

The aim of experiment 2 was to detect any change in the sense of weight caused by changing the volume of the movable portion of the MR visual stimulation.

The objective evaluation and subjective evaluation were conducted separately in this experiment.

5.2 Experimental Procedure of Subjective Evaluation

The experimental procedure was based on the Thurston’s paired comparison method. If the sense of weight was affected by the MR visual stimulation, bias should be seen in the psychological measure. There were 10 subjects in this experiment (nine males and one female). The experimental procedure is described below:

1. The subjects wear the HMD.
2. Two patterns are randomly selected from the 10 patterns shown in Table 1
3. One of the two patterns selected step (2) was superimposed onto the same real rigid object presented to subjects’ HMD.
4. The subjects asked to bend their elbows about 90 degrees and hold the real object and swing them right and left according to a metronome (100 strokes/min).
5. Repeat (3) to (4) with the remaining pattern in step (3).

6. Ask the subjects to compare these two patterns and to answer which felt heavier.
7. Sufficient breaks are provided to eliminate the effect of muscle fatigue.
8. Repeat steps (2) to (7) for the remaining combinations.

5.3 Experimental Procedure of Objective Evaluation

The subjects for the objective evaluation experiment were also five men.

1. The subjects wear the HMD and electrodes are attached on their forearms.
2. Select one pattern randomly from pattern 1, 3, 5, 6, 8, 10 in Table 1 and was superimposed onto the same real rigid object presented to subjects' HMD.
3. The subjects asked to bend their elbows about 90 degrees and hold the real object and swing them right and left according to a metronome (100 strokes/min).
4. The subject rests for 3 sec and repeat steps (3) to (4) three times.
5. Sufficient breaks are provided to eliminate the effect of muscle fatigue.
6. Steps (2) to (5) were repeated until all patterns had been selected.

5.4 Results and Discussion

Fig. 7 shows the results of subjective evaluation and it can be seen that;

1. Regardless of the height of liquid level, when the liquid CGI is shown to be moving, the object is perceived lighter than the case where the liquid is not moving.
2. Though the weight of the case is not changed, the subject feels the object is heavier when the liquid measure is increased.

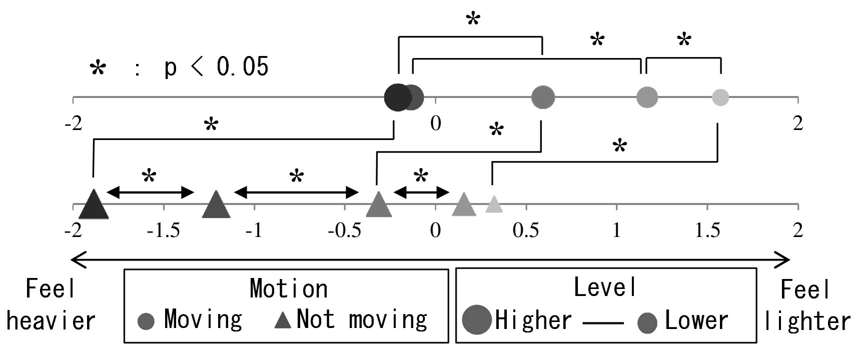

Fig. 7. Results of Experiment 2 (Thurstone's paired comparison method)

3. Fig. 8 shows the r average of the %MVC supinator in the interval. The period of analysis was 3 sec from the start to the end of the swinging motion. The figure shows that;
4. (iii) When the CGI liquid was shown to be moving, the amount of muscle activity in the supinator decreased.

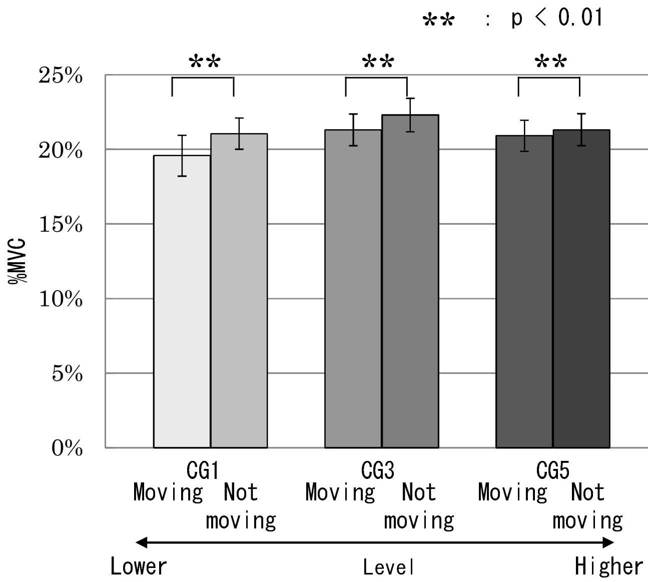

Fig. 8. Results of Experiment 2 (Average %MVC)

6 Conclusion

In this paper, we conducted experiments to examine the influence of superimposing virtual objects having movable portion in it onto real rigid objects. As a result, we confirmed that weight perception can be influenced by superimposing virtual objects though the weight of real object is not changed (experiment1), and we named this illusion the "R-V Dynamics Illusion." In Experiment 2, we examined the volume of the movable portion of the MR visual stimulation. As a result, regardless of the liquid measure, when the liquid CGI is shown to be moving, the object to be perceived lighter than the case where the liquid is not moving. We also found that the lower the liquid level become, the lighter real object is perceived.

"R-V Dynamics Illusion" may still present many unanswered questions, and hence we must conduct additional experiments to address them. For the future, we will continue to study the occurrence of this illusion in other situations.

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