An Examination of Perception of Grasping a Virtual Object in Barehanded Interaction

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***Abstract*— In this study, we focus on barehanded interaction with a virtual object in the virtual space using a head mounted display (HMD). This study examines whether a user is given a sensation, such as grasping a physical object, when the user grasps the virtual object. In the examination, we simultaneously present visual and auditory information.**

Keywords—virtual reality; perception; interaction;

I. Introduction

Recently, it is possible to acquire and display movements of user's real hands in the virtual space by development of virtual reality (VR) technology. The importance of barehanded interaction with a virtual object has been increased and such studies [1] were much conducted. However, it is difficult for a user to get a haptic sensation with a virtual object using only visual information. For this reason, studies of making use of senses besides a visual sense also need to conduct.

Our previous work [2] proposed a system with which a user operated a virtual object with user's hands. In this system that utilized an infrared sensor, hand models were displayed in the virtual space when the user place the hands above the infrared sensor. Interaction like grasping and translating the virtual object was conducted with the hand models that corresponded with movements of the user's hands. But, in this system, there was a problem that it was difficult for the user to recognize the deformation limit of the virtual object, and thus the perception of the softness of the virtual object was insufficient.

A related study [3] proposed an augmented reality (AR) system that improved a sensation of grasping a virtual object. This study examined whether a user was given pseudo-haptics like grasping a physical object by presenting not only visual information but also auditory information when the user grasped the virtual object in the AR space. As a result, this AR system improved the operability of the virtual object and the softness perception by adding auditory information to visual information.

In this study, we focus on giving a pseudo-haptic sensation to a user when the user grasps a virtual object with bare hands in the VR space. This study examines whether a sensation of grasping a virtual object is increased by presenting visual and auditory information simultaneously.

II. Our Virtual Reality System

Figure 1 shows an overview of our VR system. Our VR system is composed of a head-mounted display (HMD), an infrared sensor, headphones, a head tracking camera, and a PC. An infrared sensor is attached to the HMD. A user sits at a 50cm distance from the position of the head tracking camera and place their hands forward. Then, the infrared sensor recognizes the user's hands and 3D computer graphic (3DCG) models of the user's hands are presented on the HMD. The 3DCG hand models are able to interact a virtual object in the virtual space according to movements of the user's hands.

Figure 2 shows an image on the HMD. First, a box and an octagonal frame are presented on the HMD. The size of the box is fifteen cm long and ten cm short. The position of the box arranges at twenty cm far from the octagonal frame. The octagonal frame is a regular octagon with a side of seven cm. In our VR system, when a specific key is pressed, a virtual sphere is presented at the center of the octagonal frame. The user can deform the virtual sphere with 3DCG hand models presented on the HMD. We can a limit to a range of the deformation of the virtual sphere. When the deformation that the user performs reaches the limit, our VR System presents an auditory cue to the user. Also, with our VR system, the user can grasp, lift and move the virtual object.

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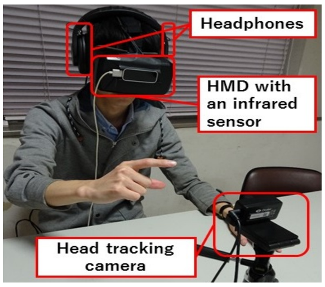


Figure 1. Our VR system

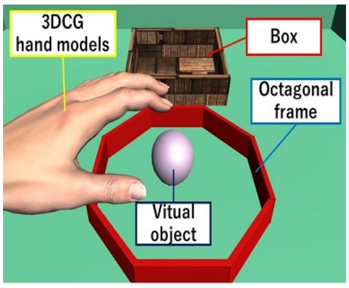
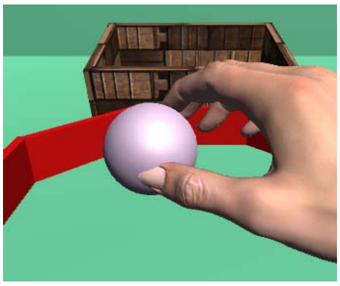
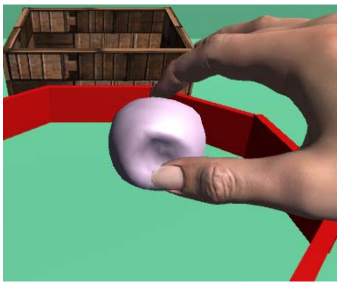


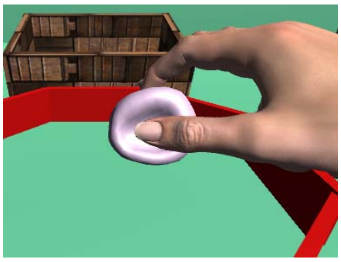
Figure 2. Image on HMD



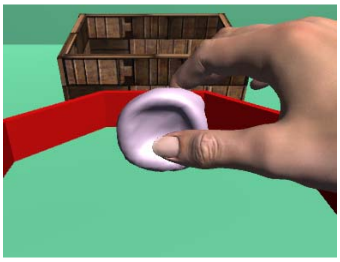
(a) Virtual object A



(b) Virtual object B



(c) Virtual object C



(d) Virtual object D

Figure 3. Four virtual spheres with different softness

A. Visual Information

We set the four limits to the deformable range of virtual spheres. The four limits make the virtual spheres different in softness. Four virtual spheres with different softness are denoted by A, B, C and D, and the differences in softness between them are shown in Figure 3. In Figure 3, a user deforms each virtual sphere.

"Virtual object A": The limit of the deformation of the virtual object A is zero. This means that, it does not deform. (Figure 3 (a))

"Virtual object B": The limit of the deformation of the virtual object B is a quarter. This means that, it deforms to a quarter of the diameter of the virtual sphere. (Figure 3 (b))

"Virtual object C": The limit of the deformation of the virtual object C is a half. This means that, it deforms to a half of the diameter of the virtual sphere. (Figure 3 (c))

"Virtual object D": The limit of the deformation of the virtual object D is three quarters. This means that, it deforms to three quarters of the diameter of the virtual sphere. (Figure 3 (d))

The visual information is images showing that the user is deforming one of these virtual spheres with the 3DCG hand models.

B. Auditory Information

The auditory information is an auditory cue presented when the virtual object is deformed to the limit. The auditory cue helps a user to perceive the softness of the virtual object. From the related study [3], we use a beep sound as the auditory cue. As a reason for using the beep sound, the beep sound has no meaning and is used for a notice of something on electronic appliances.

III. Investigations of Effects by Auditory Information

As a sensation of grasping a virtual object, we focused on perception of the softness and the operability of the virtual object. This study examined whether the perception of the softness and the operability of the virtual object were improved by presenting an auditory cue when the user deformed the virtual object to the limit in our VR system. In the following subsections, we detail various items (participants, apparatus, procedure, and design).

A. Participants

Ten volunteer participants (seven male, three female) were recruited from the local university campus. Participants ranged from 21 to 24 years old. All participant were daily users of computers. Five participants had no prior experience with our VR system. Five participants had tried the VR system in the previous study, but none was an experienced user.

B. Apparatus

The hardware consisted of an HMD (Oculus Rift DK2, Oculus VR), a head tracking camera (an accessory of the HMD), an infrared sensor (Leap Motion, Leap Motion), headphones (SRH840, SHURE) and a PC (4.0 GHz Intel Core i7-4790K with a RAM of 16.0GB). The participant wore the HMD with the infrared sensor and the headphones. By attaching the infrared sensor to the HMD, it is possible to present the hand models according to the viewpoint of the participant.

C. Procedure

First, a participant performs practice trials to get used to our VR system. In the first practice, we presented the four virtual objects one by one in ascending order of the limits of the deformation. As a task for each virtual object, the participant deformed the virtual object without lifting it and orally answered its softness. Then, the participant released the virtual object once, and again deformed it to the limit of the deformation and moved it to the inside of the box. The participant performed these tasks once without the auditory cue and once with the auditory cue, respectively. In the second practice, we randomly presented the four virtual objects without the auditory cue and those with the auditory cue. For each virtual object, the participant performed the same task that was done in the first practice. Note that if the participant needed more practice to get used to our VR system, we continued the practice trials.

After the practice trials, the participant started the main trials. As the main trials, the participant repeated three times the same practice trials in the second practice. Then, after the main trials finished, we asked the user to answer a questionnaire.

D. Design

In order to investigate effects on the perception of the softness and the operability of the virtual object by adding auditory information to visual information. We obtained objective data as well as subjective data. As objective data, we measured the time taken to answer the softness of the virtual object and the time in which the participant deformed the virtual object to the limit of the deformation and moved it into the box. As subjective data, we asked the participants to answer the softness of the presented virtual object. The softness was answered in four levels:

- the softness of “Virtual object A”
- the softness of “Virtual object B”
- the softness of “Virtual object C”
- the softness of “Virtual object D”

Also, we asked the participants to evaluate their impressions by a questionnaire at the end of the experiment. In the evaluation of subjective impressions, for each of the four virtual objects with or without the auditory cue, the participants were asked to answer the following questions:

(i) “Do you easily perceive the softness of the virtual object?”

(ii) “Do you easily operate the virtual object?”

The participants chose a score from -2 (Disagree) to 2 (Agree).

The number of each data in the main trials was 240 (= 4 virtual objects × 2 auditory information × 3 repetitions × 10 participants). The number of each data from the questionnaire was 10 (= 10 participants).

IV. RESULTS AND DISCUSSION

Figure 4 shows results measured as the objective data. In Figure4, less time means that the participants perceived the softness of the virtual object more easily and operated the virtual object more smoothly. Figure 4 (a), (b) shows the average of the time taken to answer the softness and the average of the time taken to move the virtual object into the box, respectively. As shown in Figures 4 (a), (b), for all the four virtual objects, the average time with the auditory cue was shorter than that without auditory cue and t tests indicated significant differences between with and without auditory cue.

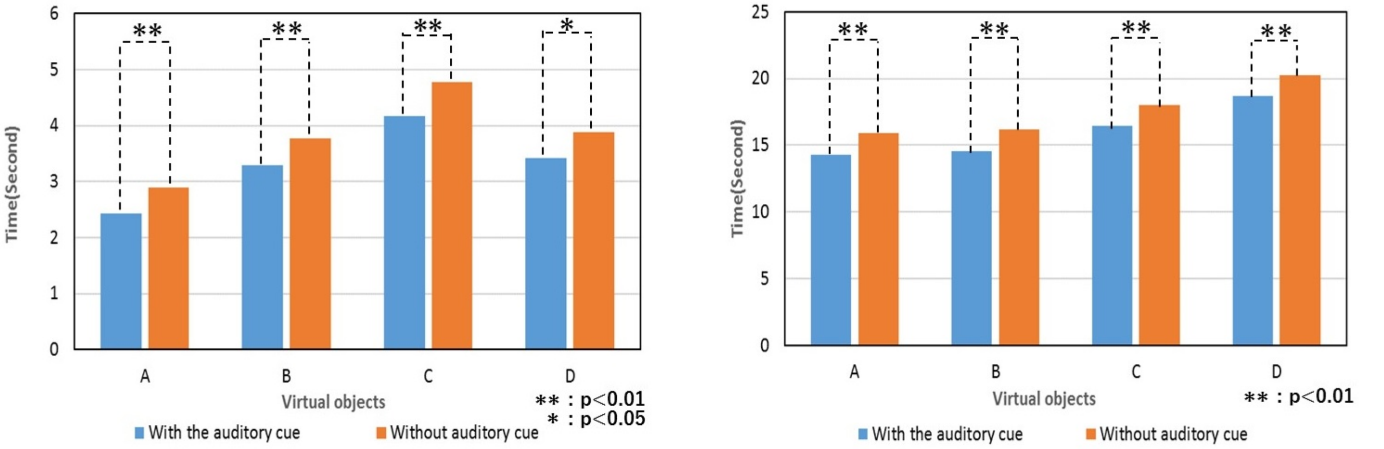
Table 1 shows the percentage of correct answers for the softness of the four virtual objects. From Table 1, the presentation of the auditory cue was effective in the perception of the softness of “Virtual object B” and “Virtual object C,” though the perception of the softness of “Virtual object A” and “Virtual object D” needed only the visual information.

Figure 5 shows results from the questionnaire. Figures 5 (a), (b) show the average of the scores for the questions (i), (ii), respectively. All participants answered that the virtual object with the auditory cue was perceived softer and operated more easily than that without auditory cue for all the four virtual objects. Also, t tests indicated significant differences between with and without auditory cue except “Virtual object A” in Figure 5(a).

As shown in Figure 4(a), Table 1 and Figure 5(a), the perception of the softness of “Virtual object A” was the easiest among the four virtual objects. Because “Virtual object A” did not deform, the participants seemed to be easier to distinguish than the deformed virtual objects. The perception of the softness of “Virtual object D” was also easier than that of “Virtual object B” and “Virtual object C.” Because “Virtual object D” had the largest limit of deformation, the participants seemed to perceive the softness of “Virtual object D” more easily than that of the other deformed virtual objects.

As shown in Figure 4 (b), when comparing these time, the time for “Virtual object A” was the shortest and time for “Virtual object B,” “Virtual object C” and “Virtual object D” followed in this order. This order was same as the increasing order of the limits of the deformation. In addition, according to an opinion from the questionnaire: “it is hard to operate the virtual object if the virtual object is too soft, and it is easy to operate the virtual object if the virtual object is less deformable,” it was suggested that because “Virtual object D” was too soft, “Virtual object D” was most difficult to operate and that “Virtual object A” which did not deform and “Virtual object B” which was slightly deformable were easy to operate.

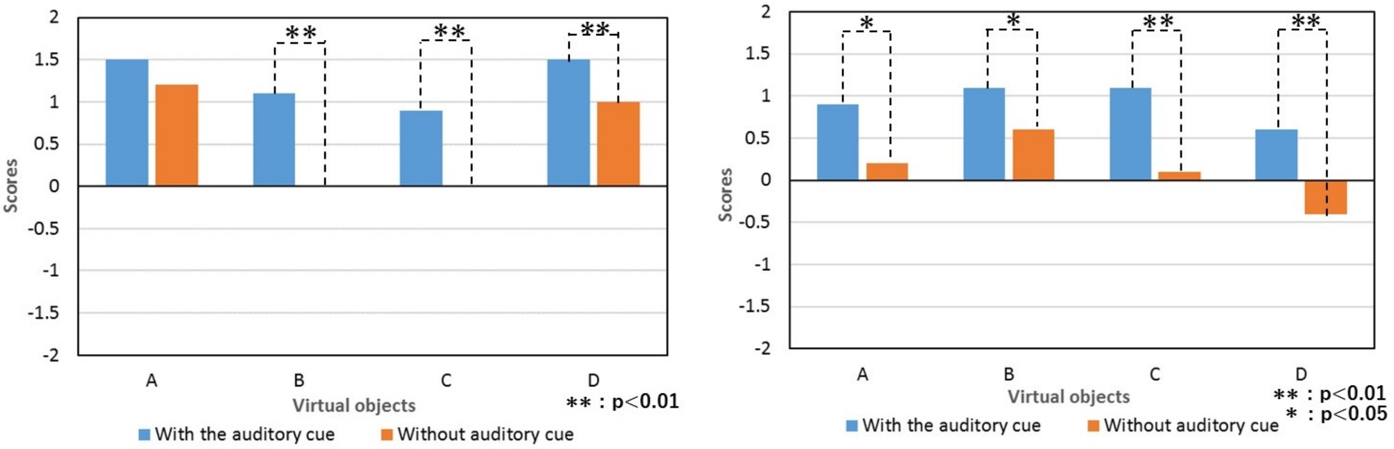
For the perception of the softness, by adding the auditory cue when the virtual object was deformed to the limits, the participants could know the limits of deformation of the virtual object. So, the participants perceived the softness more easily and moved the virtual object more smoothly with the auditory cue than they did without auditory cue. As a result, we found that the perception of the softness and the operability of the virtual object were improved by presenting the auditory cue at the limit of the deformation.



(a) The time taken to answer softness of the virtual object

(b) Time taken to move the virtual object into the box

Figure 4. Measurement results of objective data



(a) The perception of softness

(b) Operability of the virtual object

Figure 5. Evaluation results of subjective impressions

Table 1. Percentage of correct answers for softness (unit: %)

Virtual object	A	B	C	D
With the auditory cue	100	93	97	100
Without auditory cue	100	60	37	100

V. Conclusion

In this study, for the interaction between bare hands and virtual objects in the VR space, we investigated whether adding auditory cue at the deformation limit of the virtual object was effective for improving the perception of grasping deforming the virtual object. As the result of the experiment, it was shown that the perception of the softness and the operability of the virtual object were improved by adding the auditory cue at the deformation limit of the virtual object.

For future tasks, we examine auditory cues that work effective in the perception of the softness and improve the gripping behavior of virtual objects.

Acknowledgment

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