Dent-Softness Illusion in Mixed Reality Space: Further Experiments and Considerations

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ABSTRACT

When humans sense the hardness 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 onto them (MR visual stimulation). In our previous study, we first superimposed computer-generated images (CGI) on real objects, and then, applied extreme deformation to the superimposed images while the participants pressed the real objects with their fingers. The results showed that humans sense hardness differently while receiving MR visual stimulation; we named this psychophysical effect the dent-softness illusion. As the next step, in this study, we verify whether humans perceive hardness differently when pressing a real object with and without superimposed animation and whether the dent-softness illusion occurs in different parts of the body such as the finger, palm, and arm.

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

Index Terms: H.5.1 [Multimedia Information System]: Artificial, augmented, and virtual realities—

1 INTRODUCTION

Humans can sense an object's hardness when pressing the object using their body by perceiving the visual and tactile information. However, when the visual stimulation is changed, for example, in an MR environment where an animation that represents a different hardness from that of the real object is superimposed onto the real object, the perceived hardness might change.

The sense of touch is known to be affected by visual stimulation. M. Kuschel *et al.* confirmed that the visual information can influence tactile perception based on psychophysical experiments [1]. Some studies have also reported that visual stimulation affects the sense of hardness. Srinivasan *et al*. confirmed that while sensing the hardness of an object, visual information is predominant over the tactile sense when contradicting visual and tactile stimuli are presented [2]. Knorlein *et al*. [3] revealed that objects are perceived softer when force feedback is delayed.

In our previous study, we conducted an experiment to verify the influence of MR visual stimulation on the sense of hardness [4]. The results show that the illusion of an object being harder or softer than it really is occurs when the dent visualized in the MR environment differs from that on the real object. We named this psychophysical effect the dent-softness illusion.

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In the previous study, we verified whether a real object with the same hardness was perceived as harder or softer when different CGI were superimposed on it. In this paper, we describe a follow-up experiment of the dent-softness illusion. Specifically, we verify whether humans perceive hardness differently when pressing a real object with and without superimposed animation and whether the dent-softness illusion occurs in different parts of the body such as the finger, palm, and arm.

2 EXPERIMENT

2.1 Preparation

In this experiment, we focus on the following conditions:

- The real objects used in the experiment are rectangular urethanes, which are available in different hardness levels.
- The hardness of the real object is sensed by pressing the object from above.
- The presented MR visual stimulation is as follows: the part where the real object is pressed will be dented and the surrounding area will rise.

Figure 1 shows the experimental setup. By wearing a head-mounted display (HMD) containing a pair of video cameras, the subject can view stereoscopic images that are created by CGI in the scene in front of his or her eyes. The head position is constantly tracked by a six-degrees-of-freedom magnetic sensor.

The real objects used in this experiment were urethanes (INOAC Inc.) with three different hardness levels. The urethanes' dimensions for the experiment pressing with finger were 210 mm (width) × 105 mm (depth) × 50 mm (height) and for the experiment with palm and arm were 400 mm × 105 mm × 50 mm. Table 1 shows their density and hardness. We hereinafter call them Urethane 1 to Urethane 3 in the order of their hardness.

The visual stimuli presented in the experiment are CG models that are similar in shape and dimensions to the real objects. The CGI animation was deformed according to the depth of the indentation made by a subject's finger, palm, and arm in the real objects. A bend sensor was attached to the top center of the real object's surface to obtain the depth value.

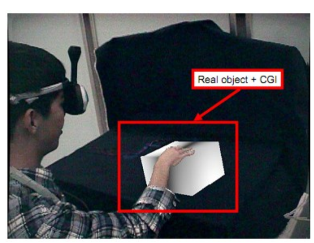


Figure 1: Experimental setup.

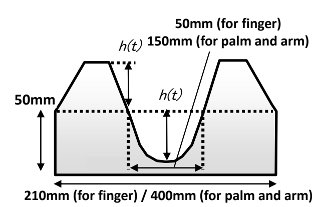
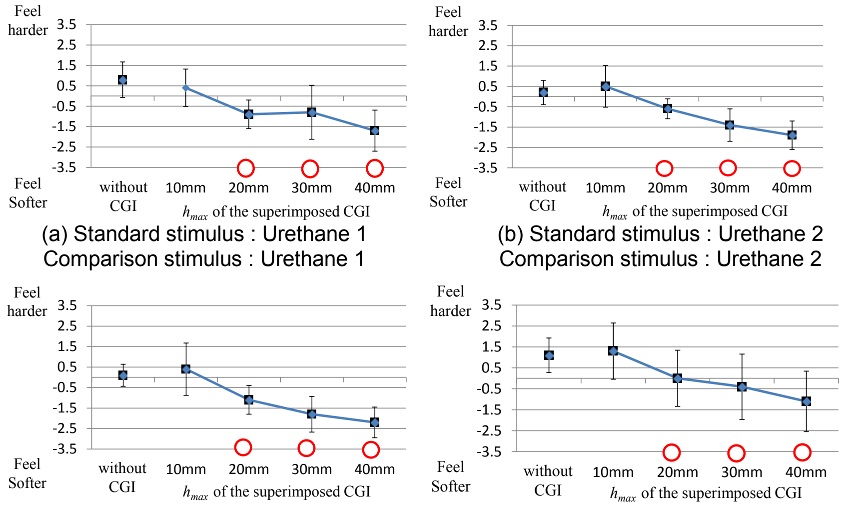


Figure 2: CG animations when pressed.

Table 1: Type of urethanes.

Name of Urethane	Density	Hardness
Urethane 1 (hard)	40 ± 4.0 kg/m^3	E 26
Urethane 2 (soft)	35 ± 3.0 kg/m^3	E 15
Urethane 3 (softer)	16 ± 1.5 kg/m^3	E 8



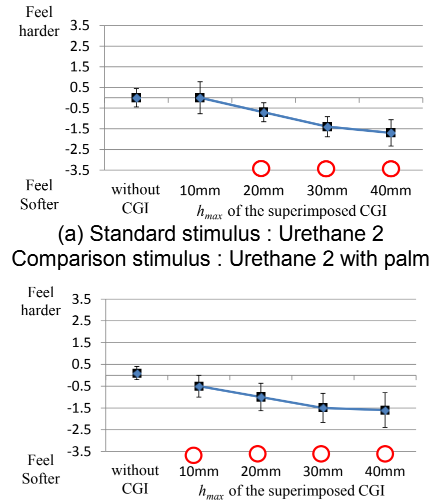
(a) Standard stimulus : Urethane 1
Comparison stimulus : Urethane 1

(b) Standard stimulus : Urethane 2
Comparison stimulus : Urethane 2

(c) Standard stimulus : Urethane 3
Comparison stimulus : Urethane 3

(d) Standard stimulus : Urethane 3
Comparison stimulus : Urethane 2

Figure 3: Results of experiment with finger pressure. The circles show when the perceived hardness differed significantly when the subjects compared a real object to an object with superimposed CGI



(a) Standard stimulus : Urethane 2
Comparison stimulus : Urethane 2 with palm

(b) Standard stimulus : Urethane 2
Comparison stimulus : Urethane 2 with arm

Figure 4: Results of experiment with palm and arm pressure. The circles have the same meaning of Figure 3.

When the top surface of the real object is pressed, the part of the CGI that corresponds to the pressed position of the real object is dented to a depth of $h(t)$, and the surrounding part rises as far as $h(t)$ (Figure 2). We obtained $h(t)$ by calculating the value of $bend(t)$, which was obtained from the bend sensor, using Equation (1). Here $bend_{max}$ is the depth value obtained by the bend sensor and h_{max} is the maximum depth of the dent.

$$h(t) = \frac{h_{max} \cdot bend(t)}{bend_{max}} \tag{1}$$

The system beeps when the urethanes are pressed to a depth of 15 mm. The subjects were required to stop pressing when the beeping sound was emitted.

2.2 Procedure

(1) Two of the three urethane objects are randomly selected.
(2) The object on the subjects' left is the standard stimulus; that on the right is the comparison stimulus.
(3) The urethane used for the standard stimulus is placed in front of the subject, who is wearing the HMD.
(4) For the comparison stimulus, the right urethane with or without superimposed CGI (CG1: h_{max} is 10 mm, CG2: h_{max} is 20 mm, CG3: h_{max} is 30 mm, or CG4: h_{max} is 40 mm) is placed in front of the subject.
(5) The subject presses the object with his or her finger until the beeping sound is emitted.
(6) The subjects are asked to compare the standard and comparison stimuli and state how hard the comparison stimulus is compared to the standard stimulus. The subjects answer using a seven-point scale −3 (very soft) to +3 (very hard).
(7) Repeat steps (1) to (6) until all combinations of the three urethanes and four CGI animations are selected.
(8) Repeat steps (1) to (7) with the palm and arm.

This sequence of experiments is applied to all the urethanes. To avoid order effects, the urethane and the presented CGI are selected at random. The number of the participants was ten.

2.3 Results

Figure 3 and 4 show some of the results of the experiments, which show the average and variance of the subjects' answers. A positive value on the ordinate means the subject tactually perceived the comparison stimulus as harder than the standard stimulus, whereas a negative value means softer. The horizontal axis shows the comparison stimulus. The leftmost point shows the result of comparison stimulus without superimposed CGI, while the other four shows the results of those with superimposed CGIs.

Figure 3 show that the value on the ordinate decreases as the indentation on the CGI animation increases. This shows that the subjects tactually perceived the object as softer than the real object. Moreover, none of the subjects perceived the comparison stimulus to be harder than the standard stimulus for any of the patterns. This means that the dent-softness illusion could give the illusion that an object is softer, but it cannot give the illusion that an object is harder. Figure 4 shows that the dent-softness illusion could occur in all body parts that we tested (fingers, palms, and arms). Figure 3 (d) shows that when the standard stimulus is Urethane 3 and the comparison stimulus is Urethane 2 with CG4 superimposed, the subjects sensed the object to be softer than it really is. We call this the "inverse phenomenon." This phenomenon occurred in all body parts that we tested.

3 Conclusion

In this paper, we conducted a follow-up experiment of the dent-softness illusion. The results of the experiment confirmed that the dent-softness illusion can also occur when comparing real objects with and without superimposed CGI and when subjects press objects with their palms and arms.

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