QUANTITATIVE ANALYSYS OF PSEUDO-HAPTICS BASED ON THREE TYPES OF HAND FORM AND TWO PHASES OF PERCEPTION

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ABSTRACT

Haptic media, as a third type of 3D media besides 3D visual and 3D audio, is essential to realize the true 3D multimedia. Recently, pseudo-haptics has gained considerable attention since it can produce a haptic feeling without specific hardware. We first categorized pseudo-haptics into three types based on perception phases and virtual hand form. A series of experiments quantitatively proved that all three types of pseudo-haptics can be perceived and exhibit interesting phenomena, e.g., pseudo-haptics might be deduced by real haptic sensation or specific visual effect.

***Index Terms*—** Pseudo-haptics, quantitative evaluation

1. INTRODUCTION

Due to the rapid progress in 3D multimedia technologies, human computer interaction has been drastically improved. Recently, haptic media, as a third type of media besides 3D visual and 3D audio, has been regarded as an essential part to realize the true 3D multimedia.

We have been studying a wide range of multimedia systems to truly support creative and intelligent human activities. They range from those used by knowledge workers (i.e. creative office workers) to those for car-exterior designers. For nearly twenty years, we have been developing design support systems by using 3D space [1] and combining 3D space and force feedback [2].

Recently, pseudo-haptics has gained considerable attention because it can produce a haptic feeling without specific hardware. Therefore, various interaction techniques that use it have emerged in several fields including entertainment.

We discuss related work and point out the lack of quantitative evaluation and the possibility of a new type of pseudo-haptics in Sections 2 and 3, respectively, and discuss a series of experiments to prove the existence of various pseudo-haptics and the possibility of the new type pseudo-haptics, as discussed in Sections 4 and 5.

2. RELATED WORK

Haptic percept can be displaced with two methods, direct and indirect. In the direct method, users have to grab hold of special equipment fixed on a desk or placed in their hands [5, 6]. The indirect method is pseudo-haptics, which was encountered a decade ago [3].

Pseudo-haptics is perceived as the result of the contradiction between visual information and somatic sensation [4]. There are many methods that take this contradiction into account. For example, a virtual hand is displayed at different positions [8] or in different sizes [9]. Pseudo-haptics can produce various haptic sensations such as hardness, weight [10], and texture [11]. Moreover Pseudo-haptics can affect human decision making [12, 14].

Although users' hands are usually displayed, in some cases, the hand is not displayed [13] or displayed but the appearance is different from that of the real-world hand [7].

3. ANALYSIS OF RELATED WORK AND PROBLEM

3.1. Analysis on perception phase

As mentioned above, pseudo-haptics is perceived as a result of the contradiction between visual information and somatic sensation.

Concerning somatic sensation, users must know how to move their hand and what kind sensation should be felt as a result of hand movement. We call this step "Phase-I".

Concerning visual information, users must to know the visual result, which should be observed as a result of hand movement in the real world. We call this step "Phase-II".

These two phases should be taken as being necessary for pseudo-haptics. Usually these two phases are automatically done and satisfied in most cases. However, as discussed in the next section, either or both phases cannot be automatically done without learning in specific cases.

3.2. Categorization based on Phase-I and Phase-II

As discussed in the previous section, Phase-I and Phase-II should be taken into account as necessary for pseudo-haptics. Therefore, research on pseudo-haptics can be categorized based on these phases.

In simple cases, both phases are satisfied without learning. For example, consider a system that displays a virtual hand and virtual ball. As long as the system displays the shape of the virtual hand and virtual ball similar to those in the real world, there is no need to learn Phase-I (learn how to move the hand) and Phase-II (learn visual response caused by the hand movement). In Table 1, this is denoted as Type-A (real hand). For example, in previous studies [4] and [14], virtual hands similar to real hands were used and the visual response was generated based on the same physics of the real world.

In some cases, learning Phase-II is necessary. We call this Type-B (slightly modified hand). Examples can be found in previous studies [9] and [13]. Since the systems, such as [9] or [13], use a slightly modified hand, the user already knows how to move it, but has to learn the visual response affected by the modified hand.

In Type-C (completely deformed hand), the learning of both Phase-I and II might be necessary in extreme cases such as a complex robot controlled by a hand shape.

Table 1. Problem and goal analyzed by shape of hand and perception phase of pseudo haptics

Shape of hand		Two perception phases of Pseudo Haptics: Phase-I Learn how to move hand	Two perception phases of Pseudo Haptics: Phase-II Learn visual response caused by hand movement	Related work (Past)	Our goal
Type -A	Real hand	No need	No need	Many studies. Qualitative evaluation only.	Quantitative evaluation.
Type -B	Slightly modified hand	No need	Necessary	Many studies. Qualitative evaluation only.	Quantitative evaluation.
Type -C	Completely deformed hand	Necessary	Necessary	(No study!)	Feasibility check. Quantitative evaluation.

3.3. Our goal

As discussed in the previous section, pseudo-haptics can be categorized into three types based on the learnability of Phase-I and Phase-II. Much research has been done on Type-A and Type-B, and various settings have been proposed, but the strength of pseudo-haptics was evaluated only qualitatively. Furthermore, there has been no research on Type-C.

As summarized in the rightmost column of Table 1, our goal was to determine the feasibility of Type-C and conduct qualitative evaluation of all types.

In other words, we wanted to determine the possibility of a new pseudo-haptic formation (Type-C) and prove the strength of pseudo-haptics quantitatively.

4. DESIGN OF EXPERIMENT AND SYSTEM

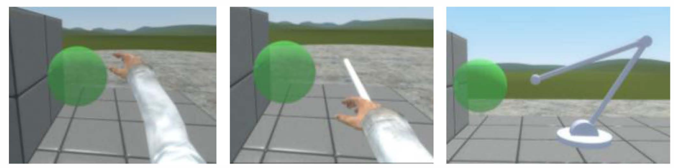
4.1. Experiment design

As shown Fig. 1, three simple environments were designed according to the definition of Types-A, B, and C.

In the Type-A setting (Fig. 1 (a)), a user's hand and a ball are displayed the same as in real world. The shape of the ball is changed according the ball's stiffness and hand position.

In the Type-B setting (Fig. 1 (b)), a short pole is attached to the hand. The user cannot touch the ball directly, but with the pole. The bend of the pole is unknown. Therefore, Phase-II learning is necessary.

In the Type-C setting (Fig. 1 (c)), a robot, instead of a hand, is displayed. The movement of the robot arm is assigned to a specific hand movement against intuition. Therefore, Phase-I and II learning are necessary.



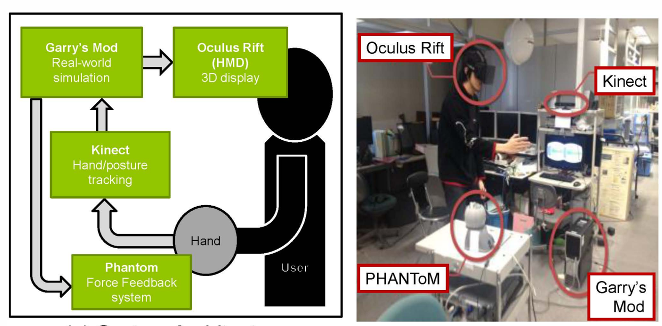
(a)Type-A: Hand (b)Type-B: Hand with pole Type-C: Robot

Fig. 1. Experimental Environment for Types-A, B and C.

4.2. Experiment system design

The architecture of the experimental system is illustrated in Fig. 2 (a). The user's hand is tracked using Kinect. The physical world of the hand, pole, robot arm, and ball was simulated using Garry's Mod. The simulation results were displayed as 3D images by using a head-mounted display (HMD) (Oculus Rift). In some of the experiments, the force was measured using a force feedback system (PHANToM Omni).

Figure 2 (b) is the current system that was used for all the experiments described in the next section.



(a) System Architecture (b) Current System

Fig. 2. Design of experimental system

5. EXPERIMENT

5.1. Overview

The experiments were designed based on the combination of the three types (Type-A, B and C) and three evaluation items (learnability of Phase-I and II and quantitative measurement). Table 2 lists all nine combinations and the experiment codes.

All experiments were conducted sequentially by four male participants who were right-handed and in their 20s.

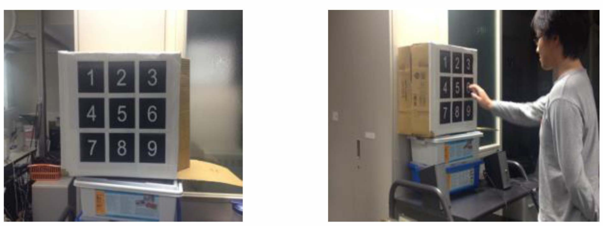
Table 2. All combinations of experiments

	Learnability of Phase-I	Learnability of Phase-II	Quantitative evaluation
Type-A	Exp-A-1	Exp-A-2	Exp-A-3
Type-B	Exp-B-1	Exp-B-2	Exp-B-3
Type-C	Exp-C-1	Exp-C-2	Exp-C-3

5.2. Experiment-A

<Exp-A-1 >

Experiment A (Exp-*-1: Exp-A-1, Exp-B-1, and Exp-C-1) involved the learnability of Phase-I, i.e., the user can move the virtual hand or robot arm with or without learning. To determine the baseline, the participants were first asked to randomly touch nine buttons in the real world, as shown in Fig. 3. The touch times are shown as “Baseline” in Fig. 4. Of course, no learning curve was observed (learning was unnecessary) and the average time was about 1 sec. This result was treated as the baseline of Exp-*-1.



(a) 3x3 real board (b) Snapshot of real touch operation

Fig. 3. Preliminary experiment

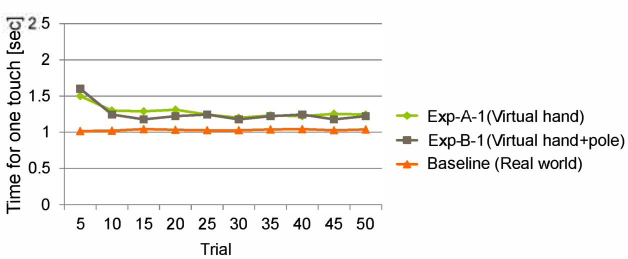


Fig. 4. Results of Baseline, Exp-A-1, and Exp-B-1

In Exp-A-1, the participants were asked to randomly touch nine buttons in a virtual world, as shown in Fig. 5. The virtual hand was controlled in exactly the same manner to the participants’ hand movements tracked using Kinect.

The touch times are shown as Exp-A-1 in Fig. 4. The touch times became stable at the third trial (Note that the data in Fig. 4 are the average of five trials). Therefore, no learning curve was observed. The average time was about 1.3 sec and was slower than the Baseline by 0.3 sec. This is because there was 0.33 sec of lag due to image processing of the PC and Kinect.

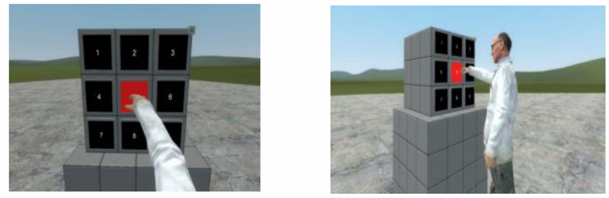

(a) 3x3 virtual board (b) Snapshot of virtual touch operation

Fig. 5. Screenshots of Exp-A-1

<Exp-A-2 >

Figure 6 (a) shows an overview of Exp-A-2. The participants were asked to push the ball by moving their right hands. The ball then yielded to the pressure. The participants observed the ball deform (Fig. 6 (a)). There were three types of balls; soft, medium, and hard. The soft ball deformed more than by actual hand movement. The medium ball deformed in exactly the same manner as that by actual hand movement. The hard ball deformed less than by actual hand movement.

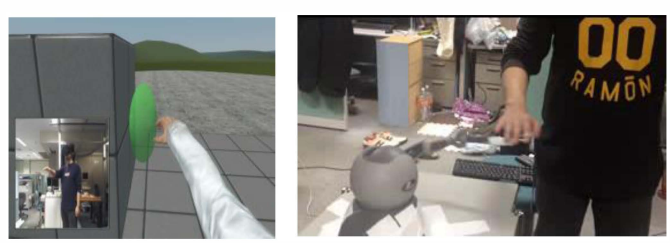
The participants were given force feedback by connecting their index fingers to PHANToM with a string, as shown in Fig. 6 (b). The strength of the force feedback was 0, 200, 400, 600, 800, 1000 mN. The maximum force feedback was displayed when the ball was deformed to half its size.

There were 3 type balls and 6 types of force feedback. Therefore, the total combination was 18.

The procedure of Exp-A-2 was as follows.

(Step 1) The participants were asked to touch the ball and memorize the softness or hardness of the ball for one minute. As explained earlier, there were 18 settings, which were randomly used.

(Step 2) The display (HMD) was shut down so that the participants could not see anything. Then they were asked to recall the softness or hardness of the ball. First, a random force feedback value was displayed using PHANToM then the participants were continuously asked whether the current feedback was larger, the same, or smaller than the force they memorized earlier. If the answer was "smaller" or "larger", the displayed force was changed by 50 mN.



(a) Overview (b) Force feedback by using PHANToM

Fig. 6. Overview of Exp-A-2

Therefore, we obtained 18 data points for each participant. Figure 7 summarizes all the data. The more force feedback was given, the less difference was observed among the three types of balls. This means that the visual display plays only a small part in haptic display when the real haptic is given.

The dotted red circle in Fig. 7 clearly and quantitatively proves the existence of pseudo-haptics.

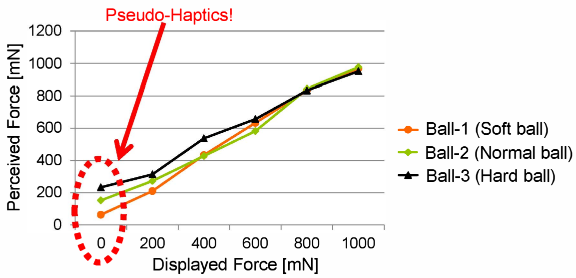


Fig. 7. Results of Exp-A-2.

<Exp-A-3>

In Exp-A-3, we added two balls. One was extremely soft and the other was extremely hard. The five balls were extremely soft, soft, medium, hard, and extremely hard, defined by the ratio between the deformed size of the ball and hand movement, e.g., 4:1, 2:1, 1:1, 1:2, 1:4.

The procedure of Exp-A-3 consisted of two steps, similar to Exp-A-2. In Step 1, no force feedback was given through PHANToM. Step 2 was the same as in EXP-A-2. Namely, EXP-A-3 was only for pseudo-haptics setting. Figure 8 shows the results, which also clearly and quantitatively prove the existence of pseudo-haptics and show the linear tendency.

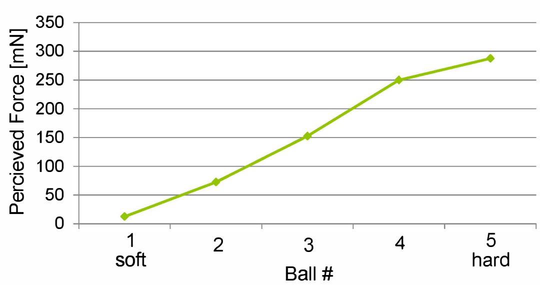


Fig. 8. Results of Exp-A-3

5.2. Experiment-B

<Exp-B-1>

The participants were asked to touch nine virtual buttons by using a pole attached to their hand, as shown in Fig. 9.

The touch times are shown as "Exp-B-1" in Fig. 4. The tendency was almost the same to that for "Exp-A-1". Therefore, no learning curve was observed. In Exp-A-1, the modification of hand shape was so small (pole only) that no learning was necessary, as summarized in Table 1.

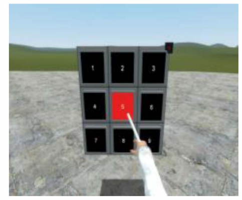


Fig. 9. Snapshot of Exp-B-1

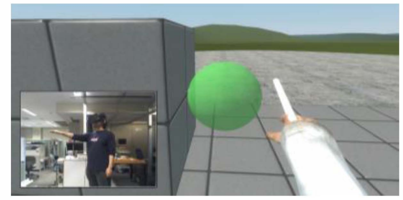


Fig. 10. Overview of Ex-B-2

<Exp-B-2>

Exp-B-2 involved Phase-II. The purpose was to determine whether the participants could learn the visual response of the pole and ball. Both the pole and ball deformed, so the participants had to learn the visual response against the given pressure.

The same five balls as in Exp-A-3 and five poles of 20, 30, 40, 50 and 60 cm with the same hardness were used.

The participants were randomly given two balls and asked to determine which ball was harder by using a pole that was also given randomly. One trial consisted of 10 judges of 20 balls by several poles.

The number of wrong answers gradually decreased, as shown in Fig. 11. Compared to Fig. 4, there was a definite learning curve, but the learning was possible because at the 9th trial (actually 90 touches and answers); there were no wrong answers.

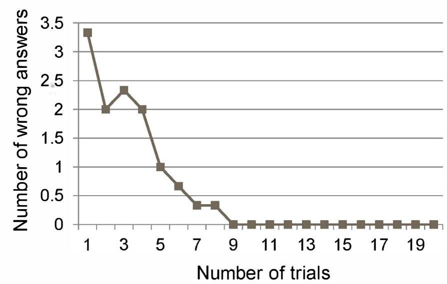
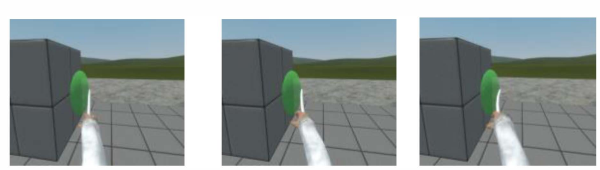


Fig. 11. Results of Exp-B-2

The results suggest the necessity of Phase-II learning, as shown in Table 1, and in some cases (hand and pole), such learning is possible.

<Exp-B-3>

Exp-B-3 involved trying to quantitatively analyze pseudo-haptics. Five types of balls, which were the same as those in Exp-A-3, and three types of poles (hard, medium and soft) were used, as shown in Fig. 12. Note that both poles and balls deformed.



(a) Hard pole (b) Medium pole (c) Soft pole (easily bends)

Fig. 12. Degree of modification of pole and ball

The procedure of EXP-B-3 was as follows.

(Step 1) The participants were asked to touch the ball with the pole, as shown Fig. 12, and memorize the softness or hardness of the ball for one minute. There were 3 types of poles x 5 types of balls = 15 settings, which were randomly used.

(Step 2) The display (HMD) was shut down so that the participants could not see anything. They were then asked to recall the softness or hardness of the balls in the same manner as in Exp-A-2.

Figure 13 shows the results. Generally, the harder the ball was, the more haptic feeling was perceived. This can be seen to clearly and quantitatively prove the existence of pseudo-haptics. The exceptions were the two points inside the dotted circle (i.e. hard ball and medium/soft pole). At first glance, this seems strange. However, the two points are important. It can be assumed that the force felt by the hand was weaken by the bending of the soft and medium poles. This may also be validated by the fact that this was not observed for the hard pole.

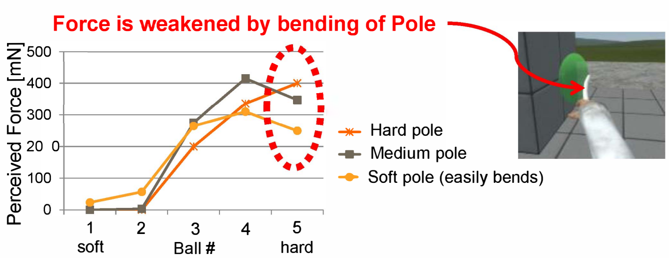


Fig. 13. Results of Exp-B-3

5.3. Experiment-C

<Exp-C-1 >

The participants were asked to touch nine virtual buttons by controlling a robot arm, as shown in Fig. 14. The movement of the robot arm was assigned to a specific hand movement, as shown in Fig. 15

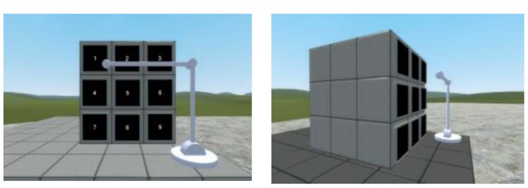


Fig. 14. 3x3 virtual board in Exp-C-1

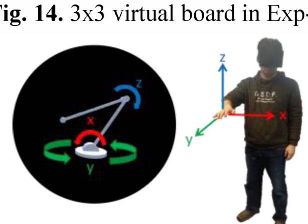


Fig. 15. Correspondence between hand movement and robot movement

The touch times are shown in Fig. 16. Compared with Figs. 4 and 11, there was a very slow learning curve, but learning was at least possible because, at the 50th trial (actually 450 cycles), the time converged to 2.0 sec, which was much longer than the 1.0 sec of real hand and 1.3 sec of virtual hand w/wo pole. This is probably due to the fact that the distance of the hand movement was much longer than in other cases.

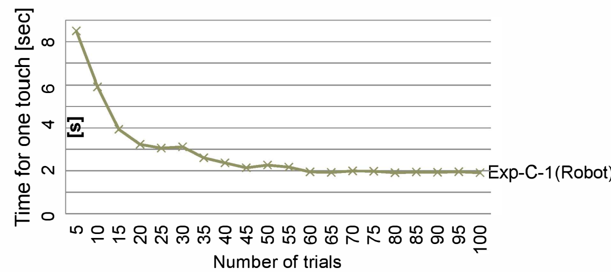


Fig. 16. Results of Exp-C-1

<Exp-C-2 >

Experiment-C-2 involved Phase-II. The purpose was to determine whether the participants could learn the visual response of a robot arm and ball. Both the robot arm and ball deformed, so the participants had to learn the visual response against the pressure given by hand.

The same five balls as in Exp-A-3 were used, and a ball was placed in three positions (up, left, and right), as shown in Fig. 13.

The participants were randomly given two balls in two positions then asked to determine which ball was harder by using the robot arm. One trial consisted of 10 judges of 20 balls.

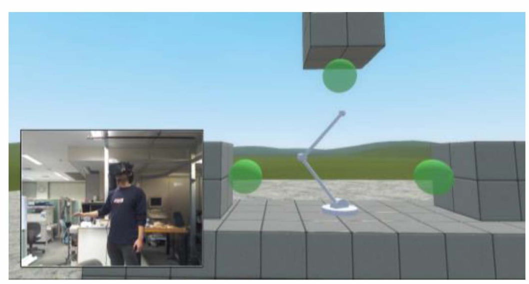


Fig. 17. Overview of Exp-C-2

The number of wrong answers gradually decreased, as shown in Fig. 11.

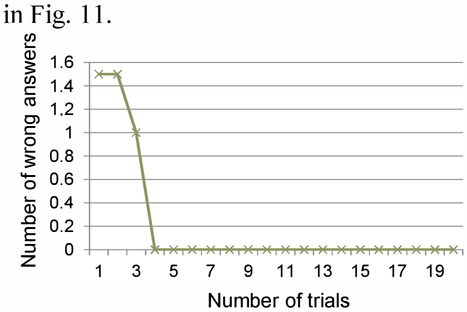


Fig. 18. Results of Exp-C-2

<Exp-C-3 >

Experiment-C-3 involved trying to quantitatively analyze pseudo-haptics. The procedure of Exp-C-3 was similar to that of Exp-B-3; five types of balls and one robot arm.

Figure 19 shows the results, which clearly and quantitatively prove that Type-C can be an effective type of Pseudo-Haptics, even though the effect is weaker than Types-A and -B. Note that Fig. 19 displays the data of Type-C as well as Types-A and B.

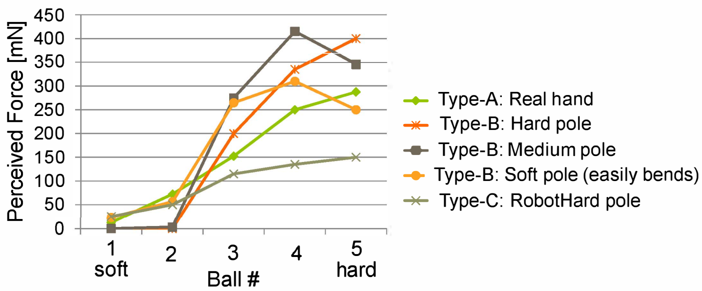


Fig. 19. Results of Exp-C-3 (including Exp-A-3 and Exp-B-3)

6. SUMMARY

Haptic media, as a third type of 3D media besides 3D visual and 3D audio, is essential to realize the true 3D multimedia. Recently, pseudo-haptics has gained considerable attention since it can produce a haptic feeling without specific hardware.

First, pseudo-haptics was categorized into three types; Type-A (real hand), B (slightly modified hand), and C (completely deformed hand) based on the learnability of Phase-I (learn how to move hand) and Phase-II (Learn visual response caused by hand movement).

Second, a series of experiments was conducted to quantitatively prove that pseudo-haptics can be perceived for all three types. Although Type-C requires the learning of Phase-I and Phase-II, weak pseudo-haptics was observed.

Finally, two interesting phenomena were found. One is that the visual display plays only a small part in the haptic display when real haptics is given. The other is that pseudo-haptics might be deduced by a specific visual effect, which actually enhances the pseudo-haptics in specific environments.

We are now conducting an experiment involving more participants and in various environments for Types-B and C.

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