

Evaluation of a device reproducing the pseudo-force sensation caused by a clothespin

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ABSTRACT

A pseudo-force sensation can be elicited by pinching a finger with a clothespin. When the clothespin is used to pinch the finger from the palm side, a pseudo-force is felt in the direction towards the palm side, and when it is used to pinch the finger from the back side of the hand, the pseudo-force is felt in the extension direction. Here, as a first step to utilizing this phenomenon in human-machine interfaces, we developed a device that reproduces the clothespin phenomenon and confirmed the occurrence rate of the pseudo-force sensation.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; *HCI theory, concepts and models*.

KEYWORDS

Clothespin, Human interface, Pseudo force, Virtual reality

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1 INTRODUCTION

When a person touches an object, they receive several different kinds of haptic information about the object, including size, surface texture, softness, warmth, and so on. The reproduction of haptic information in virtual reality (VR) environments is expected to be important to the degree of realism, and such information may be useful in augmented reality (AR) environments where users interact with real objects.

Several haptic devices have been developed for VR applications. These include external skeletal devices [3][13] and gripping devices

[4][6]. As these methods typically require large equipment and complicated mechanisms, several researchers have attempted to make devices that were "wearable". One such device could involve the presentation of a pseudo-force sensation via pressure to the skin on the fingerpads [5][9][14][17].

Such haptic devices typically cover the fingerpads completely, which impedes sensation of the real object. However, some researchers have reported methods of tactile presentation in which the fingerpads are not covered, but where the device is attached to the middle phalanx [10][12][18]. However, these methods were aimed at the presentation of tactile cues, and were not intended to provide realistic force illusions. Other proposals have been centered on electrical muscle stimulation [15][16], which can present clear force sensations at the fingertip without covering the fingerpad. However, the use of electrical stimulation is accompanied by several challenges, such as the stability of the sensation.

A pseudo-force sensation can be elicited by pinching a finger with a clothespin [11]. When the clothespin pinches the finger from the palm side, the pseudo-force is felt in the direction in which the hand naturally bends, and when it pinches the finger from the back of the hand, the pseudo-force is felt in the extension direction (Figure 1). Because this phenomenon can occur without covering the fingerpad, it might be useful in AR applications. In this paper, we describe a device that reproduces the clothespin phenomenon and test the occurrence rate of the pseudo-force sensation.

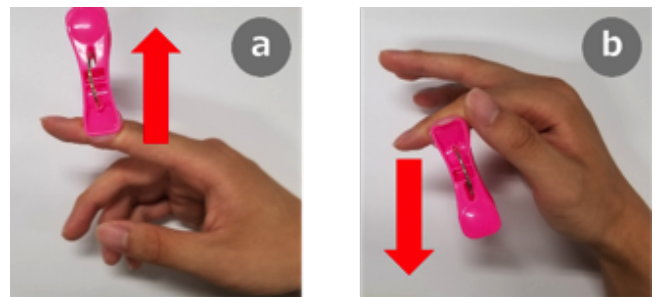


Figure 1: The direction of the pseudo-force sensation: (a) extending, pinched from the back of the hand, (b) bending, pinched from the palm side of the hand.

*Both authors contributed equally to this research.

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2 DEVICE DESIGN

2.1 Movement of clothespin

To reproduce the pseudo-force phenomenon, we focused on the movement of the clothespin. Although the mechanism of this phenomenon has not been investigated, we confirmed that compression and skin deformation occur when the clothespin is used to pinch the hand. A previous study showed that postural error is induced by deforming the skin of the fingers in the shear direction [2]. Sensory nerves are stimulated by mechanical stimulation of the tendons, eliciting a sense of motion [1]. We speculated that one or both of these processes are involved in the pseudo-force phenomenon. Therefore, in reproducing the phenomenon, we presented compression and deformation of the skin. Regarding the compression position, reexamination of data from a previous study with multiple comparisons via the Kruskal-Wallis test and the Dunn-Bonferroni test (Figure 2) revealed that stimulation of the middle part of the finger produced the strongest illusion. Thus, we decided to use the middle phalanx in the present study. Using a springy measure (SANKO, 5 kgf maximum), we found that the compression force of the clothespin on the fingers was about 2 kgf.

2.2 Reproducing the phenomenon

To incorporate the phenomenon into a haptic device, a controllable device is needed that can present the illusion in an arbitrary direction. The device should be lightweight so that it has a minimal effect on the task in the real space. Thus, it is necessary to select an actuator that is maximally lightweight. Kon et al. reported that a pseudo-force sensation could be presented using a pneumatic actuator (a balloon that expands because of changes in air pressure). Specifically, the device could be used to present compression and skin deformation to the head or lumbar region [7][8]. Based on this study, we used a lightweight pneumatic actuator installed between an aluminum outer frame and a stainless steel inner plate. Driving the pneumatic actuator causes the plate to move and press the finger, leading to skin deformation (Figure 3). The balloon used for the pneumatic actuator was 20 mm in length by 20 mm in width. The air supply from the air motor (SC 3710 PML, SEJOO MOTION) was set to have a response time of 700 ms and the air release via a solenoid valve was set to have a response time of 300 ms (SC415GF 6.0 V, SEJOO MOTION). When the air valve was opened, an almost instantaneous force, similar to that produced by the clothespin, was generated. Rubber bands that did not cause skin deformation were used to attach the device to the finger. A 3-mm-thick sponge was laid between the stainless steel plate and the skin to reduce discomfort.

The compressive force of the device was measured using a film-type force sensor (SWITCH SCIENCE). Two pressure sensors were placed between the finger and the sponge layer. We found that the fingers were sandwiched with a compression strength of about 1.2 kgf. Although this is slightly weaker than the clothespin compression (2 kgf), we decided to experiment with this strength. When no pressure was applied, the fingers received a force of about 640 g. When the device was attached to the back side of the hand, there was a pseudo-force sensation in the extension direction, and when it was attached to the palm side, there was a pseudo-force sensation in the bending direction (Figure 4).

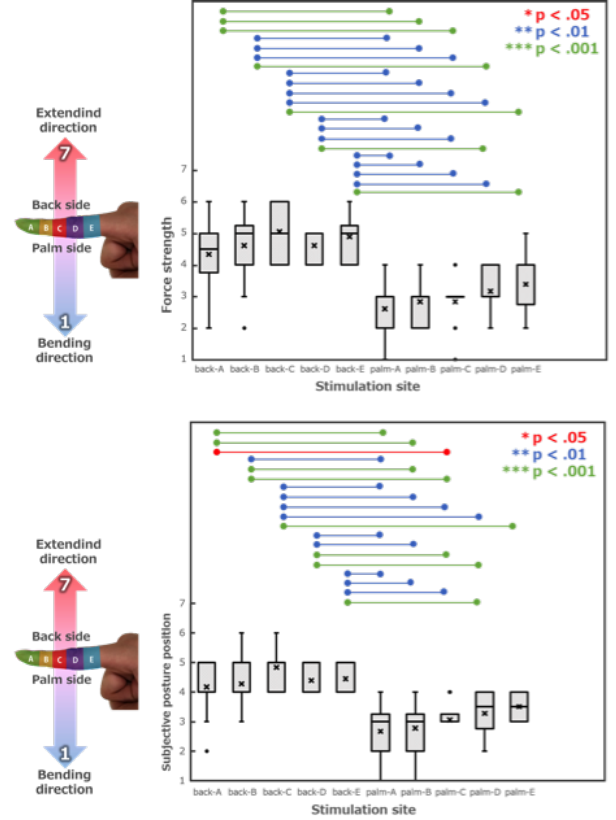


Figure 2: Occurrence frequency of clothespin phenomenon in the index finger: The finger was divided into five parts from A to E, and the clothespin was attached at each part from the back or palm side of the hand. Participants reported the strength of the force sensation and stated the subjective position of the finger using a 7-level Likert scale. Data were from [11] with new statistical analysis.

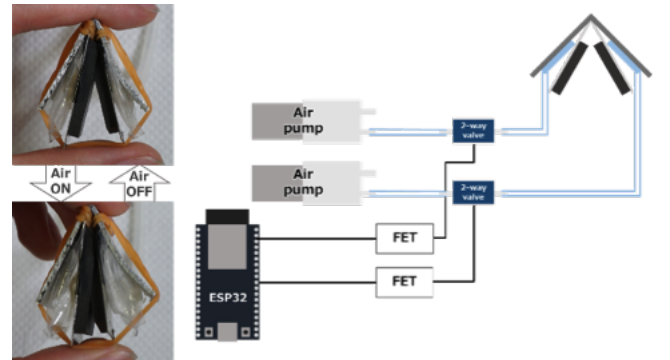


Figure 3: Device configuration.

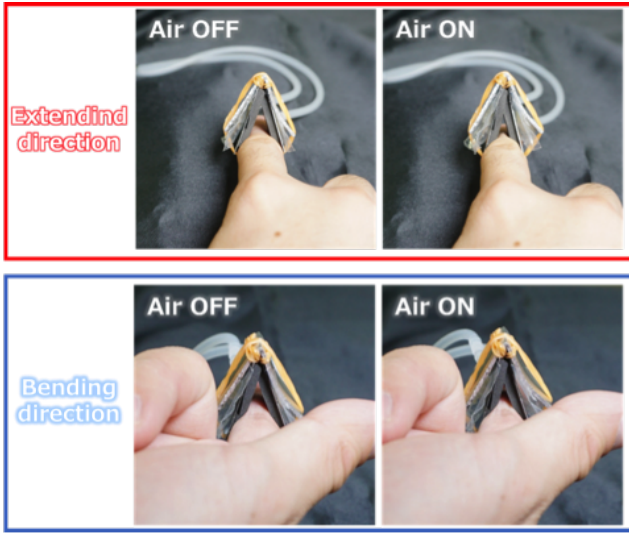


Figure 4: When the device was attached from the back side of the hand: When the pneumatic actuator was driven, the skin was deformed so as to gather towards the back side of the hand. When the device was attached from the palm side of the hand: When the pneumatic actuator was driven, the skin was deformed so as to gather towards the palm side of the hand.

3 EXPERIMENT

3.1 Outline of experiment

In this experiment, we confirmed whether the new device produced the same phenomenon as the clothespin, and quantified the strength of the sensation.

3.2 Experimental conditions

The participants were ten men (21 to 28 years old, all right-handed). They wore headphones during the experiment to block external sounds. The experimenter instructed the participants to keep their eyes closed, and not to resist the force sensation that they felt during the experiment. The device was attached to the middle phalanx, which was where the clothespin phenomenon had been strongest. There were four stimulation conditions in this experiment: Two device attachment conditions (from the back side or palm side of the hand) and two air pump conditions (off and on).

3.3 Experimental procedure

As shown in Figure 5, each participant placed their right forearm on an armrest and the experimenter attached the device to the middle phalanx of their index finger. After attaching the device, the experimenter presented white noise, which served to mask external sounds and to signal the start of the stimulation. The participants were asked to state the strength of the force sensation and the subjective position of the finger using a 7-level Likert scale. Number 4 was set as “does not feel the force sensation in either direction” for the former and “does not move in any direction” for the latter. Number 7 indicated that the participant felt the force or

posture towards the back side of the hand, and number 1 indicated that the force or posture was felt towards the palm side. There were five repetitions for each of the two pressure conditions and two pinching directions, for a total of 20 trials. The order of the trials was randomized.



Figure 5: Experimental setting

3.4 Experimental results

Figure 6 shows the experimental results with respect to force sensation. The vertical axis represents the subjective force strength and the horizontal axis represents the stimulation condition. “Back” and “Palm” on the horizontal axis indicate whether the device was installed from the back or from the palm side of the hand, and “Air” indicates that air pressure was applied. We analyzed the data using the Kruskal-Wallis test, and confirmed the presence of a main effect ($\chi^2(2) = 160.0736, p < 0.001$). Multiple comparisons via the Dunn-Bonferroni test revealed significant differences between the Back (Air) and Back (None) conditions, etc., as shown in Figure 6. Figure 7 shows the subjective posture of the finger. The vertical axis represents the subjective force strength and the horizontal axis represents the stimulation condition. We analyzed the data using the Kruskal-Wallis test, and confirmed the presence of a main effect ($\chi^2(2) = 104.079, p < 0.001$). Multiple comparisons via the Dunn-Bonferroni test revealed significant differences between the Palm (Air) and Palm (None) conditions, etc., as shown in Figure 7.

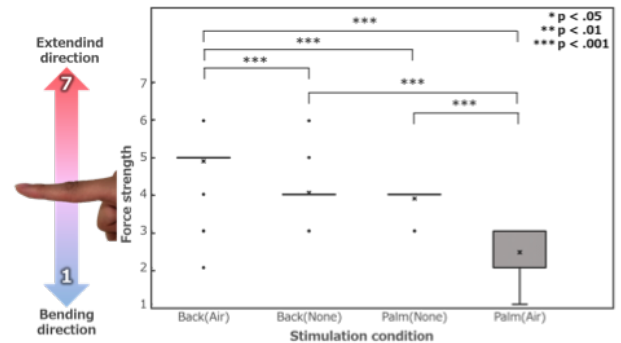


Figure 6: Subjective force strength.

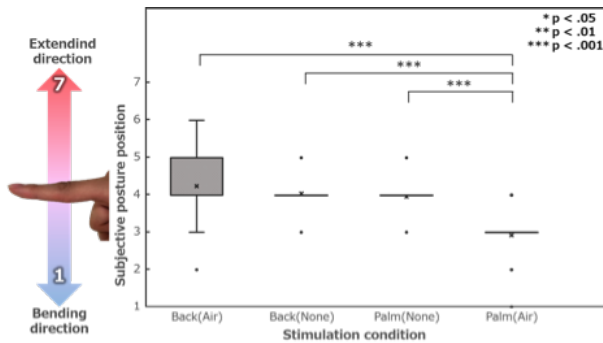


Figure 7: Subjective finger posture.

4 DISCUSSION

Our data indicate that pneumatic compression elicited the pseudo-force sensation in both the extension and bending directions. However, with respect to subjective finger posture, participants did not consistently perceive that the finger had moved in the extension direction. This may have occurred because the drivable angle in the extension direction from the initial posture (in which we asked participants to relax as best as possible) was not the same as that in the bending direction, and the former is harder to perceive compared with the latter. After the main experiment, we asked the participants who felt a weak sense of force and motion in the extension direction to intentionally move their fingers. As a result, they commented that the sensation in the extension direction became easier to interpret. Thus, in the application of this phenomenon in VR or AR, it may be necessary to drive the device in accordance with the active finger motion of the user.

5 CONCLUSION

In this paper, we investigated whether a pneumatic compression device could produce a pseudo-force sensation phenomenon comparable to that elicited by a clothespin. As a result, we confirmed that participants could perceive the pseudo-force sensation in both the extension and bending directions during pneumatic compression. However, subjective posture was only affected in the bending direction.

In future work, we plan to verify the occurrence of the clothespin phenomenon during active user finger motion, and eventually apply this phenomenon to VR or AR environments.

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