Perceptual Force on the Wrist Under the Hanger Reflex and Vibration

Takuto Nakamura[1(✉)], Narihiro Nishimura[1], Taku Hachisu[2], Michi Sato[1], Vibol Yem[1], and Hiroyuki Kajimoto[1]

[1] The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu, Tokyo, Japan
{n.takuto,n-nishimura,michi,yem,kajimoto}@kaji-lab.jp
[2] The University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi, Ibaraki, Japan
hachisu@ai.iit

Abstract. The hanger reflex is a phenomenon that accompanies illusory force sensation and involuntary head rotation when the head is fastened with a wire hanger. This phenomenon is also observed on the wrist, and is expected to apply when using small and simple haptic feedback devices. However, issues of slow response and the requirement for large actuators still remain. Here, we discuss the discovery of a new phenomenon: the perceptual force from the hanger reflex is enhanced when a vibration is also presented. If we can control the strength of the perceptual force induced by vibration, a smaller, simpler, and higher response device might be achieved, because a vibrator can be controlled easily. This paper reports details of this phenomenon, and the effect of the frequency and amplitude of the vibration on the strength of the perceptual force. We observed that low frequency (50–100 Hz) vibrations efficiently enhanced the perceptual force, and that participants perceived a stronger perceptual force if the vibration of a greater amplitude was presented. These results suggest that the enhancement of the perceptual force is controllable and can be applied to construct a new type of wearable haptic device.

Keywords: Hanger reflex · Haptic display · Perceptual illusion · Skin stretch

1 Introduction

While haptic cues are considered important in many areas such as sports training, remote control and VR gaming, conventional haptic devices commonly require large and expensive equipment, which limit their potential application areas.

To solve this problem, some methods have been proposed for presenting a "perceptual force" by using perceptual illusions [1–3]. These methods allow the use of compact and inexpensive devices, because they do not need to reproduce an actual force. However, there is a limitation on the strength of the perceptual force induced by these devices.

To produce a strong perceptual force using a perceptual illusion, we focused on the "hanger reflex". The hanger reflex is a perceptual illusion in which the head rotates involuntarily when it is fastened with a wire hanger [4]. During the hanger reflex,

F. Bello et al. (Eds.): EuroHaptics 2016, Part I, LNCS 9774, pp. 462–471, 2016.
DOI: 10.1007/978-3-319-42321-0_43

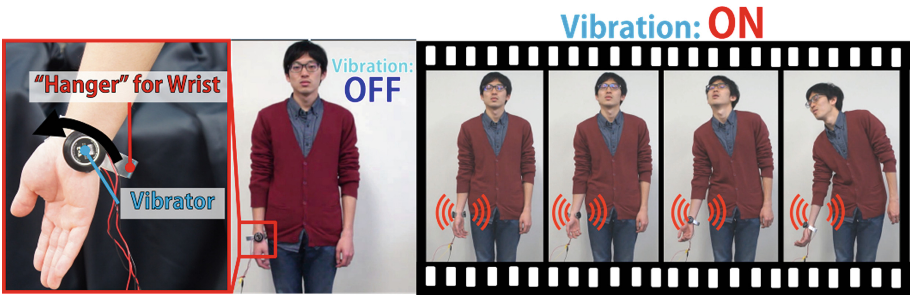

Fig. 1. Presenting the vibration on the wrist under the hanger reflex: The force caused by the hanger reflex is enhanced, and it induces the wrist rotation

people feel a strong perceptual force, and rotate their heads. Because of its strength of the perceptual force, the hanger reflex has been expected to apply to pseudo force display. However, the device is still too large to control skin deformation, and time response is poor.

While seeking solution to these issues, we discovered a new phenomenon: the strength of the hanger reflex on the wrist is enhanced by additionally applying vibration (Fig. 1). Because the enhancement changes by changing the characteristics of the vibration, this phenomenon might be used to control the strength of the hanger reflex with a simple setup, and the time response of the device might be improved. Based on these experiments, this paper reports the details of this phenomenon, and the basic characteristics of its frequency and amplitude dependence.

2 Related Work

Nowadays, several force displays are commercially available [5–7], which present an actual force to the user through a grounded device. While these devices succeed in producing a high-quality force sense, they have several limitations such as limited workspace and relatively high cost. Several wearable force displays, which do not limit the movement of the user, have also been proposed [8], but these devices typically become complicated.

To achieve small and low-cost devices, techniques that use perceptual force illusions have been proposed. Visually induced haptic sensations, known as pseudohaptics, have been intensively studied [9, 10]. Amemiya and Gomi [2] and Rekimoto [3] used the non-linearity of human perception and produced force sensations by presenting asymmetric acceleration. These devices do not present a physical force, but do induce a perceptual force by stimulating other senses, thereby achieving small and low-cost devices. However, the strength of the perceptual force induced by these devices is limited, and hence, applications using these devices are limited, such as navigation.

To produce a strong perceptual force using a perceptual illusion, we focused on the hanger reflex. The hanger reflex is a perceptual force illusion in which the head rotates involuntary when it is fastened with a wire hanger. Sato et al. [4] found "sweet spots" on the head by measuring the pressure distribution on the head under the hanger reflex and showed that the direction of lateral skin stretch contributes to the direction of the hanger reflex [11]. In addition, the hanger reflex has been observed not only on the head but also on the wrist and waist [12].

Previous studies [13] have reported that skin deformation generates force perception, and this has been used as an interface [1, 14–16]. The hanger reflex might be regarded as one type of such illusion, but it is characterized by its strong force that induces the involuntary head rotation. Sato et al. [4] developed a device that reproduces the pressure distribution of the hanger reflex, and controls the direction of the hanger reflex. Nakamura et al. [17] also developed a similar device for the wrist, which presses the "sweet spots" on the wrist found by measuring the pressure distribution. However, these devices use actuators that are large in size and poor in response time to present pressure.

3 System for Enhancement of the Perceptual Force from the Hanger Reflex

Our new finding was that a vibration applied to the hanger enhances the hanger reflex. To test this finding, we developed a new device. The device mainly consists of a "hanger device" that generates the hanger reflex on the wrist (Fig. 2), and two vibrators (HaptuatorMark2, Tactile Labs Inc.). The "hanger device" is made of an aluminum bar bent in a U-shape, and it is adjustable to fit to any size of wrist. A urethane sheet is placed inside the device, which directly contacts the skin to protect it (Fig. 2). Figure 3 shows how the hanger device generates the hanger reflex.

1. First, the user mounts the hanger device on their wrist.
2. Second, by rotating the device slightly, the device is deformed elastically, and pushes the "sweet spots" of the hanger reflex found in the previous work [17]. Because the vectors of the pressure from the device do not cancel each other, the device generates rotational moment.
3. The device tries to rotate the wrist, but the friction between the device and the wrist stops the device, and deforms the skin of the wrist.
4. As a result of a perceptual illusion, the user perceives the skin deformation as an external rotational force.

The vibrators mounted on the hanger device are able to vibrate the whole device, so that the user perceives both the vibration and hanger reflex on the wrist. An audio

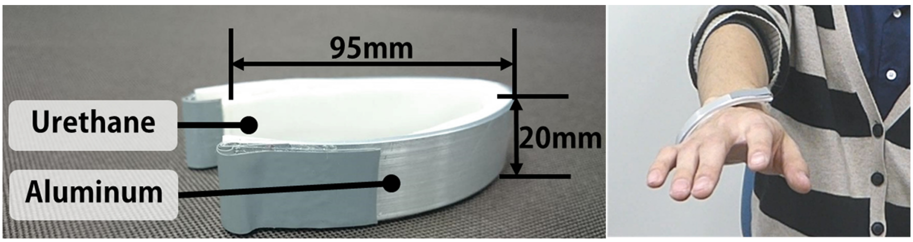

Fig. 2. The "hanger device" that induces the hanger reflex on the wrist

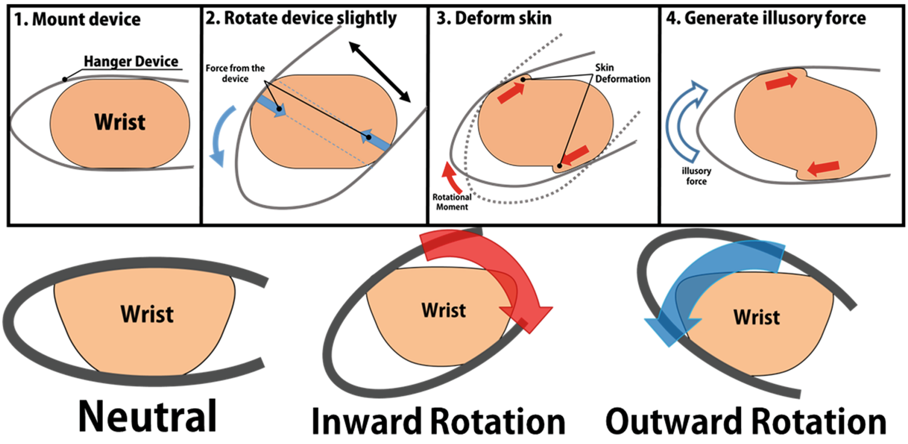

Fig. 3. Mechanism of the hanger device: by changing the direction, the device can induce illusory force in two directions

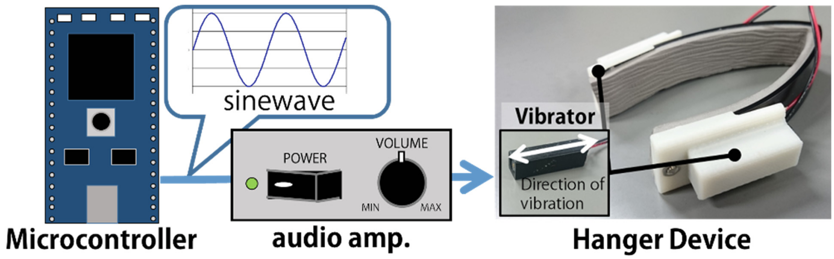

Fig. 4. System configuration of the hanger device used in the experiment

amplifier (RSDA202, RASTEME SYSTEMS Inc.), and a microcontroller (mbed LPC1768, NXP Inc.) are used to generate the vibrations (Fig. 4).

In our preliminary test with several laboratory members, they felt the enhanced force only while the vibration was being presented. They also commented that "when the acceleration amplitude of the vibration is increased, the enhancement rate of the force was also increased". When we turned the vibration on and off periodically, we observed that the participants involuntarily rotated their wrist every time they received stimulation. Based on these comments and observations, we expect that this phenomenon is capable of solving the issues of previous hanger reflex devices.

4 Experiment 1: Effect of Frequency

The purpose of the first experiment was to investigate the effect of vibration frequency on the perceptual force of the hanger reflex. We compared the perceptual strength of force between the hanger reflex only condition and the hanger reflex with vibration

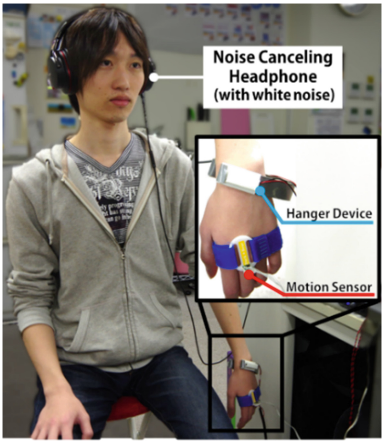

Fig. 5. Participant and mounted devices

condition using the method of magnitude estimation. This experiment has been approved by the ethics committee of the University of Electro-Communications.

Setup. The system described in the last section (Fig. 4) was used to present vibration and the hanger reflex to the participants' wrist. We prepared four sinusoidal waves of different frequencies and the same acceleration amplitude of 0.20G. To standardize the acceleration amplitude of the waves, we used the accelerometer to measure the acceleration and adjusted the value to 0.20G. To measure the posture of the hand during the experiment, we mounted a motion sensor (MPU-9150, InvenSense Inc.), which consists of a 3-axi acceleration sensor, a 3-axi gyro sensor, and a 3-axi geomagnetic sensor, on the back of participants' hand (Fig. 5).

Procedures. The participants were six laboratory members (all male, age range: 21 to 25). Before the experiment, all participants confirmed whether the hanger reflex occurred on their wrist. Only those who experienced the effect of the hanger reflex on their wrist participated the experiment. Before starting the experiment, we instructed the participants to wear the hanger device on their left wrist, and to mount the motion sensor on their back of their left hand. To mask auditory cues, we asked the participants to wear noise canceling headphones and listen to white noise. During the experiment, we instructed the participants to wait while allowing their left arms to sag, to relax, and not to look at their hands. The vibration presentation time was six seconds.

After presentation, we asked the participant to estimate the perceived force as a numerical value. They were asked to assume that the perceived force from only the hanger reflex (initial state) was "100", and to express the perceived force from the hanger reflex superimposed by the vibration as a numerical value. For example, if the participant felt a stronger force from the hanger reflex plus vibration than the force from the hanger reflex alone, the participant would give an answer like "110" or "120". Conversely, if the participant felt a weaker force, they would give an answer like "90" or "80".

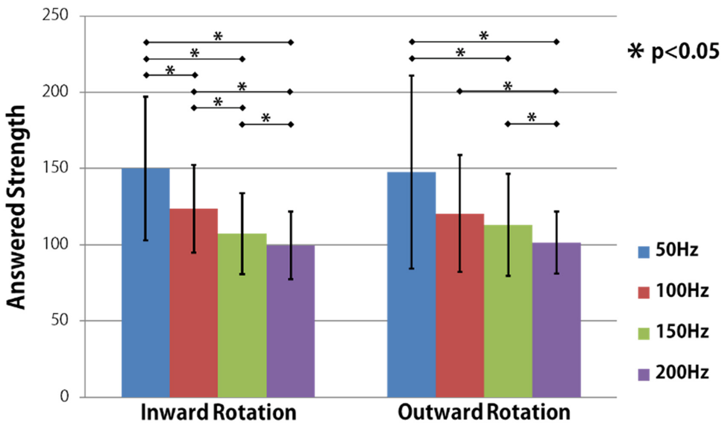

Fig. 6. The average values of answered strength in each frequency

Conditions. There were two directions of hanger reflex (inward and outward), four frequencies of vibration (50 Hz, 100 Hz, 150 Hz, and 200 Hz), and each condition was repeated ten times. Therefore, 80 trials were conducted for each participant. We divided the experiment into an "inward session" and an "outward session", and took at least a two-hour rest interval between each session. In each session, the vibration frequencies were presented randomly. The order of the two sessions was balanced between participants. To prevent adaptation to the vibration, the participants rested for at least 30 s after every eight trials.

Results and Discussion. Figure 6 shows the results of the experiment. The vertical axis represents the average value of the answers, and the horizontal axis represents the frequency of the vibration. The error bar represents the standard deviation. Because of the number of participants, we analyzed the data with non-parametric tests. As heteroscedasticity was observed, we used the Kruskal-Wallis test for this analysis. The results of the test showed a main effect of each session (df = 3, $\chi^2 = 93.5564$, $p < 0.01$ and df = 3, $\chi^2 = 36.9429$, $p < 0.01$ for the inward and outward sessions, respectively). Post-hoc tests (Steel-Dwass test) showed that for the inward hanger reflex, there were significant differences between 50 Hz and {100 Hz, 150 Hz, 200 Hz}, 100 Hz and {150 Hz, 200 Hz}, and 150 Hz and {200 Hz} ($p < 0.05$). For the outward hanger reflex, there were significant differences between 50 Hz and {150 Hz, 200 Hz}, 100 Hz and {200 Hz}, and 150 Hz and {200 Hz} ($p < 0.05$).

From the results, the answered value was the highest when the frequency of vibration was 50 Hz for both the inward and outward directions. The value became lower and was almost equal to the standard (100) when the frequency was 200 Hz. Several participants also reported that a vibration with a lower frequency gave a stronger perceptual force. Conversely, they reported that a vibration with a higher frequency reduced the perceptual force. These results and reports suggested that a vibration with a lower frequency efficiently enhances the perceptual force from the hanger reflex.

5 Experiment 2: Effect of Amplitude

In the previous experiment, we investigated the effect of the frequency of the vibration on the phenomenon. In the next experiment, we investigated the effect of vibration amplitude. This experiment has been approved by the ethics committee of the University of Electro-Communications.

Setup and Procedures. Experiment 2 was conducted with the same setup and procedures as in Experiment 1. The participants were six laboratory members (all male, age range: 21 to 24) who confirmed that the effect of hanger reflex occurred their wrists. Vibration frequency was fixed to 50 Hz.

Conditions and Participants. The conditions for this experiment were two directions of hanger reflex (inward and outward), and seven acceleration amplitudes of the vibration (0.0625G, 0.0884G, 0.125G, 0.1768G, 0.25G, 0.3536G, and 0.5G). Each condition was repeated five times. Therefore, 75 trials were conducted for each participant.

The same way as in Experiment 1, we divided the experiment into an "inward session" and an "outward session", and the time interval between these sessions was at least two hours. In each session, the order of the vibrations' conditions was random. To prevent the wrist from adapting to the vibration, the participants rested for at least 30 s after every seven trials.

Results and Discussion. Figure 7 shows the results of the experiment. The vertical axis represents the average value of the participants' answers, and the horizontal axis represents the acceleration amplitudes of the vibration. The error bar represents the standard deviation. The data were analyzed using non-parametric tests and heteroscedasticity was observed. The Kruskal-Wallis test showed that the main effect of

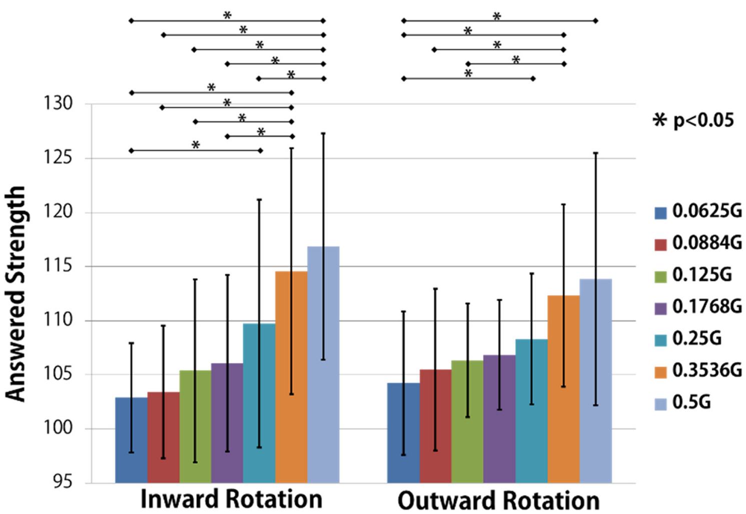

Fig. 7. The average values of answered strength in each acceleration amplitude

acceleration amplitude was significant for each session (df = 6, $\chi^2 = 58.0891$, $p < 0.01$ and df = 6, $\chi^2 = 34.7814$, $p < 0.01$ for the inward and outward sessions, respectively). Post-hoc tests (Steel-Dwass test) showed that, for the inward hanger reflex, there were significant differences between 0.5G and {0.0625G, 0.0884G, 0.125G, 0.1768G, 0.25G}, 0.3536G and {0.0625G, 0.0884G, 0.125G, 0.1768G}, 0.25G and {0.0625G} ($p < 0.05$ for all). For the outward hanger reflex, there were significant differences between 0.5G and {0.0625G}, 0.3536G and {0.0625G, 0.0884G, 0.125G}, and 0.25G and {0.0625G} ($p < 0.05$ for all).

The graph suggests that the participants perceived a stronger perceptual force if a vibration of a greater amplitude was presented. According to post-experimental questioning, there were some participants who noticed multiple strengths of the perceptual forces and were able to clearly distinguish them. Thus, these results and reports suggest that we can control the strength of the perceptual force by changing the acceleration amplitude.

6 Discussion

In both experiments, the average values were greater than "100", a perceptual force caused by the hanger reflex alone, and it suggests that the vibration really enhances the perceptual force caused by the hanger reflex. In addition, in Experiment 1, the perceptual force increased as the frequency of the presented vibration lower. In Experiment 2, the perceptual force increased as the amplitude of the presented vibration increased. These results suggest both frequency and amplitude can change the enhancement of the perceptual force. Therefore, to change the enhancement more efficiently, the user should change both frequency and amplitude simultaneously. To present greater force, the frequency should be lower and the amplitude should be bigger. Also, to enhance a little, the frequency should be higher and the amplitude should be smaller.

In addition to the discussion of experiments, we will discuss why this phenomenon occurs when both hanger reflex and vibration were presented based on the experimental results above. Nonlinearity of perception is a possible candidate for this illusion. The induction of pseudo-forces using the nonlinearity of perception has been researched by presenting asymmetrical acceleration [2] [3]. In these studies, a strong and short acceleration was perceived as stronger than a weak and long acceleration, resulting in a directional force illusion. In our case, the skin is deformed in one direction by the hanger reflex, which provides a kind of offset. When the vibration is superimposed on the skin, the vibration increases or decreases the offset skin deformation. At this time, the participants might perceive a stimulus that increases skin deformation as stronger, either by perceptual reasoning or via the nonlinearity of skin elasticity. Thus, without using an asymmetric vibration, our method succeeded in presenting a unidirectional force illusion.

The other possible candidate is illusory kinesthesia, which is a phenomenon reported by Goodwin et al. [18]. It is a perceptual illusion that occurs when a vibration of around 70 Hz is presented to the tendon, resulting in a feeling as if the vibrated part of the body was bent, even it was not. In addition, Cordo et al. [19] reported that if people perceive passive motion during illusory kinesthesis, the sensation of the illusory kinesthesis is enhanced. In our study, we presented the vibration to the wrist, not to the elbow that previous studies presented. However, there is a muscle called the "pronator quadratus" in the wrist that twists the arm. Thus, the enhancement of the force from the hanger reflex occurs because of illusory kinesthesia. Furthermore, as reported by Cordo et al., passive motion during the illusory kinesthesis strengthen the illusion. In our case, the hanger reflex might have acted as this passive motion, and enhanced the perceptual force.

7 Conclusion and Future Work

In this paper, we reported the characteristics of the enhancement phenomenon that can be used to control the strength of the perceptual force. This phenomenon enhances the perceptual force induced by the hanger reflex when a vibration is also presented to the wrist. From the results of the experiment investigating the effect of frequency, we observed that a 50 Hz–100 Hz sinewave enhanced the perceptual force the most. The results of the experiment investigating the effect of amplitude suggested that the participants perceived a stronger perceptual force if a vibration of a greater amplitude was presented. These results suggest the possibility of controlling the perceptual force by changing the amplitude of the presented vibration.

In future work, we will develop a device that controls the perceptual force, as well as the direction. Figure 8 shows a sample design of the device using the phenomenon we reported in this paper. To control the user's wrist bidirectionally, we use two hanger reflex devices, and wear them in the opposite direction to counter the effect that each one provides. After that preparation, vibration is presented to only one of these two hanger devices, and the user will perceive the enhanced force and rotate their hand. The validity of this design has already been confirmed in a preliminary experiment.

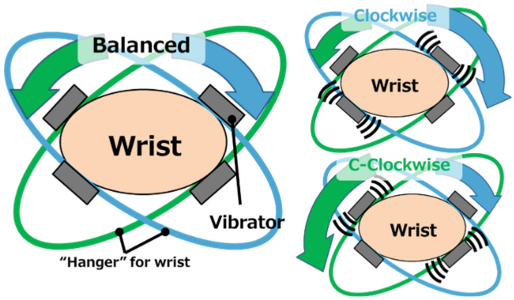

Fig. 8. Description of the conceptual device

Acknowledgment. This work was supported by JSPS KAKENHI Grant Number 15K12079.

References

1. Minamizawa, K., Prattichizzo, D., Tachi, S.: Simplified design of haptic display by extending one-point kinesthetic feedback to multipoint tactile feedback. In: Proceedings of IEEE Haptics Symposium 2010, pp. 257–260 (2010)
2. Amemiya, T., Gomi, H.: Distinct pseudo-attraction force sensation by thumb-sized vibrator that oscillates asymmetrically. In: Proceedings of EuroHaptics 2014, pp. 88–95 (2014)
3. Rekimoto, J.: Traxion: a tactile interaction device with virtual force sensation. In: Proceedings of 26th ACM Symposium User Interface Software and Tech (UIST2013) (2013)
4. Sato, M., Matsue, R., Hashimoto, Y., Kajimoto, H.: Development of a head rotation interface by using hanger reflex. In: Proceedings of 18th IEEE International Symposium Robot Human Interactive Communication (RO-MAN), pp. 534–538 (2009)
5. Massie, T.H., Salisbury, J.K.: The PHANToM haptic interface: a device for probing virtual objects. In: Proceedings of 3rd Symposium on Haptic Interface for Virtual Environment and Teleoperator Systems, pp. 295–300 (1994)
6. Harders, M., Barlit, A., Akahane, K., Sato, M., Szekely, G.: Comparing 6dof haptic interfaces for application in 3D assembly tasks. In: Proceedings of EuroHaptics 2006 (2006)
7. Kadlecek, P.: Overview of current developments in haptic APIs. In: Proceedings of CESCG 2011 (2011)
8. Yang, G., Ho, H.L., Chen, W., Lin, W., Yeo, S.H., Kurbanhusen, M.S.: A haptic device wearable on a human arm. In: 2004 IEEE Conference on Robotics, Automation and Mechatronics, pp. 243–247 (2004)
9. Kuschel, M., Luca, M.D., Buss, M., Klatzky, R.L.: Combination and integration in the perception of visual-haptic compliance information. IEEE Trans. Haptics **3**, 234–244 (2010)
10. Lécuyer, A.: Simulating haptic feedback using vision: a survey of research and applications of pseudo-haptic feedback. Presence Teleoperators Virtual Environ. **18**, 39–53 (2009)
11. Sato, M., Nakamura, T., Kajimoto, H.: Movement and pseudo-haptics induced by skin lateral deformation in hanger reflex. In: Proceedings of SIG TeleXistence 5th Workshop (2014). (in Japanese)
12. Nakamura, T., Nishimura, N., Sato, M., Kajimoto, H.: Application of hanger reflex to wrist and waist. In: Proceedings of IEEE Virtual Reality (VR) 2014, pp. 181–182 (2014)
13. Edin, B.B., Johansson, N.: Skin strain patterns provide kinaesthetic information to the human central nervous system. J. Physiol. **487**, 243–251 (1995)
14. Solazzi, M., Provancher, W.R., Frisoli, A., Bergamasco, M.: Design of a SMA actuated 2-DoF tactile device for displaying tangential skin displacement. In: Proceedings of IEEE World Haptics Conference (WHC 2011), pp. 31–36 (2011)
15. Kuniyasu, Y., Sato, M., Fukushima, S., Kajimoto, H.: Transmission of forearm motion by tangential deformation of the skin. In: Proceedings of 3rd Augmented Human International Conference (2012)
16. Yem, V., Kuzuoka, H., Yamashita, N., Ohta, S., Takeuchi, Y.: Hand-skill learning using outer-covering haptic display. In: Auvray, M., Duriez, C. (eds.) EuroHaptics 2014, Part I. LNCS, vol. 8618, pp. 201–207. Springer, Heidelberg (2014)
17. Nakamura, T., Nishimura, N., Sato, M., Kajimoto, H.: Development of a wrist-twisting haptic display using the hanger reflex. In: Proceedings of 11th Advances in Computer Entertainment Technology Conference (ACE2014) (2014)
18. Goodwin, G.M., Mccloskey, D.I., Matthews, P.B.C.: The contribution of muscle afferents to kinesthesia shown by vibration induced illusions of movement and by the effects of paralyzing joint afferents. Brain **95**, 705–748 (1972)
19. Cordo, P.J., Gurfinkel, V.S., Brumagne, S., Flores-Vieira, C.: Effect of slow, small movement on the vibration-envoked kinesthetic illusion. Exp. Brain Res. **167**, 324–334 (2005)