The Rice Haptic Rocker: Comparing Longitudinal and Lateral Upper-Limb Skin Stretch Perception

Janelle P. Clark(✉), Sung Y. Kim, and Marcia K. O'Malley

Rice University, Houston, TX 77005, USA
janelle.clark@rice.edu

Abstract. Skin stretch, when mapped to joint position, provides haptic feedback using a mechanism similar to our sense of proprioception . Rocker-type skin stretch devices typically actuate in the lateral direction of the arm, though during limb movement stretch about joint angles is in the longitudinal direction. In this paper, human perceptual performance in a target-hitting task is compared for two orientations of the Rice Haptic Rocker. The longitudinal direction is expected to be more intuitive due to the biological similarities, creating a more effective form of haptic feedback. The rockers are placed on the upper arm, and convey the position of a cursor among five vertically aligned targets. The longitudinal orientation results in smaller errors compared to the lateral case. Additionally, the outer targets were reached with less error than the inner targets for the longitudinal rocker. This result suggests longitudinal stretch is more easily discerned than laterally oriented stretch.

1 Introduction

Skin stretch devices of various forms have been successfully studied for several applications, by stretching the skin to varying of degrees and directions to convey information to the user. The motivation behind all haptic devices is to provide easily understood information through the sense of touch. For skin stretch in particular, it remains an open question if the orientation of the stretch impacts perception. In this work, the Rice Haptic Rocker is used to compare the user's perception in its current configuration, stretching skin laterally from side to side, or a longitudinal configuration, stretching skin along the length of the arm.

Haptic devices are becoming an increasingly important form of communication, utilizing the sense of touch to offload visual, auditory, or situational information. For example, customizable vibration patterns can be used for phone notifications, or a user can be informed through the controller of a gaming system of some danger to the avatar. In the research community, the applications of haptic interfaces are more extensive, in both actuation mode and application, to create easily perceived and understood information, for instance allowing users to increase skill performance in surgery [19] or receive directional guidance [21]. In addition to vibratory modes mentioned above [9], haptic modes such as squeeze

D. Prattichizzo et al. (Eds.): EuroHaptics 2018, LNCS 10894, pp. 125–134, 2018.
https://doi.org/10.1007/978-3-319-93399-3_12

[6], pneumatic [2], and normal forces [3] have also been studied, along with the skin stretch mechanisms which are the focus of this work.

Skin stretch devices have been developed to provide user feedback, and can be separated into those actuating on the fingertip, wrist, and arm. For finger-tip devices, the applications vary between virtual mass and forces [18,20], friction rendering [22], and directional cues [13,14]. Among them, longitudinal, lateral, and combination devices are present, as well as devices using both directions with success. The workspace of these devices is significantly smaller than those on the wrist and arm, attributable to the density of mechanoreceptors in the fingertips. For this work, fingertip devices are useful to review, however the results presented here are expected to only apply to more gross movements on the wrist and arm.

Wrist mounted skin stretch devices also actuate in lateral [8] and combined lateral and longitudinal systems [16,24], with similar application to the fingertip designs, guidance and force feedback. The mechanisms vary in design, in [24], several motors rotate a silicone ball on either side of the wrist. A bracelet of four rocker-shaped actuators in [8] create a variety of possible cooperative or antagonistic pairs. There are two pads in [16] which can move both in the longitudinal direction and rotate about the base of a lever, creating a lateral effect. However in this experiment, where the device was intended for force feedback, users reported wanting to move their arm in the direction of the stretch cue. This type of user response has made skin stretch successful in guidance and positional error applications listed above, as well as for devices on the arm utilized for prosthetic control. .

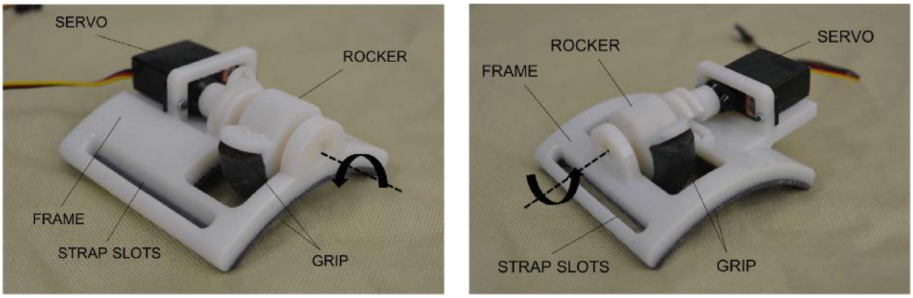
The remaining skin stretch devices discussed here are designed to actuate on the upper arm. For those presented, the feedback is mapped to positional information, either absolute angular position or positional error. The device in [23] has a unique design, with two small contacts rotating about an axis between them, creating a twisting stretch on the arm to indicate angular position errors. The portable device in [7] has a small protrusion mounted to a plate allowing to move both laterally and longitudinally to convey directional cues. Rather than a compact device, the system in [1] has cables for each prosthetic finger run from the prosthesis to a terminating button adhered to the forearm. The longitudinal stretch from the cables serve to indicate the hand aperture. The Rice Haptic Rocker has a rocker design similar to those in the wrist design presented in [8], which at Rice was preceded by [5]. It was first introduced in combination with the Pisa/IIT SoftHand to complete object discrimination tasks for a grasping spheres with a prosthetic hand [4]. One rocker is mounted laterally to convey the relative aperture of the hand. These devices are similar in the method they use to communicate with the user, however the actuation scheme varies considerably.

When selecting a type of haptic feedback for a given task, the concept of modality matching has been beneficial by suggesting the haptic mode should reflect the type of information it is used to convey [15,17]. Research in the biological mechanisms behind proprioception in humans suggest that, in addition to muscle spindles, joint position information is in part realized through the repeatable patterns of skin stretch about the joints [11,12]. Then skin stretch is particularly suitable for positional information, and demonstrated through the body of work previously referenced.

We hypothesize, in consideration of the biological mechanisms, stretch in the longitudinal direction is more intuitive to a user than lateral stretch. In this work, the perceptual accuracy of a target task is assessed using the Rice Haptic Rocker in its initial lateral configuration compared to a revised longitudinal one. Results of this work serve to compare the relative effectiveness of two stretch directions for haptic feedback on the upper arm.

2 Device Description

The Rice Haptic Rocker is a haptic device consisting of a rocker shaped geometry with a high friction interface with the skin. Its rotation by a servo creates a tangential force, stretching the skin as the servo is actuated. It has been proposed and utilized already in the lateral orientation, as described in [4], where the axis of rotation is parallel to the length of the arm and the skin is stretched from side to side. In this work, it is compared to the longitudinal direction, where the skin is stretched along the length of the arm and the axis of rotation is perpendicular to it, see Fig. 1.



(a) Lateral Rocker Orientation (b) Longitudinal Rocker Orientation

Fig. 1. The rocker is mounted in two orientations in order to compare user perception between the previously studied lateral orientation to the proposed longitudinal orientation.

The frame and rocker are made of a hard ABS-like plastic and 3-D printed by a Connex Objet 260 printer. The contact surface of the rocker is a half inch diameter silicone rubber, different than the rectangular neoprene foam used in [4], in order to increase comfort. The frame holds a servo (Hitec HS-5070 MH), which actuates the rocker, with two socket head screws and nuts (M1.6 $\times$ 0.35 mm). The assembly of the frame, rocker, and servo are placed on the upper arm with the rocker toward the outside of the arm.

3 Methods

Participants were asked to complete a virtual navigational task to determine the effects of different skin stretch orientations on sensory perception. The navigation was facilitated by skin stretch feedback in lateral or longitudinal directions. We hypothesize that stretch in the longitudinal direction would garner a lower error value than stretch in the lateral direction.

3.1 Experimental Participants

The experiment included twenty-three able-bodied subjects (age 21.5 ± 2.1 years, 4 female, one left handed). The participants did not claim any physical or cognitive impairment that could interfere with their ability to follow the instructions of the study, nor any pathology that could affect tactile sensation of the upper arm. The methods and procedures described in this paper were carried out in accordance with the recommendations of the Institutional Review Board of Rice University with written informed consent obtained from all users.

3.2 Experimental Set-Up

The rocker was placed and secured on the upper arm of the subject with a frame, held with a Velcro strap. The tightness of the device was dependent on the comfort of the subject, but sufficient to facilitate skin stretch with the rocker with no slipping. During the assessment, the participant was seated at a workbench in front of a monitor and keyboard, see Fig. 2. Once seated, the participants were asked to place their arm on the table in a relaxed position, with the rocker assembly secured on their right arm. The arm and rocker were visually occluded by a black curtain to cause participants to rely only on the haptic sensations of the rocker. Headphones with pink noise prevented possible auditory cues from the servo actuation.

Participants moved the cursor to the desired position using the 8 and 2 keys, and indicating a complete trial by pressing the enter key when they believed the target had been reached. The assessment environment was implemented with MATLAB, Simulink and QUARC visualization software, and sampled at 1000 Hz. Five targets positioned in a vertical line were displayed on the monitor, all equally spaced at 48, 24, 0, −24, −48 units, as shown in Fig. 3. In each trial, one of the four non-center targets would brighten, indicating the desired target the participant should navigate toward. Starting from the center target, the cursor moved a uniform distance with each key press within each trial. Across trials the increment at which the cursor moved varied randomly between 1, 2, 3, 4, or 6 units per key press, to prevent the participants from counting key presses rather than relying solely on the stretch. The rocker position on the arm is proportional to the cursor position on the screen. The visibility of the cursor was dependent on the experimental block, as described in Sect. 3.3. Each target and increment combination was shown an equal number of times in each experimental block with a randomized order.

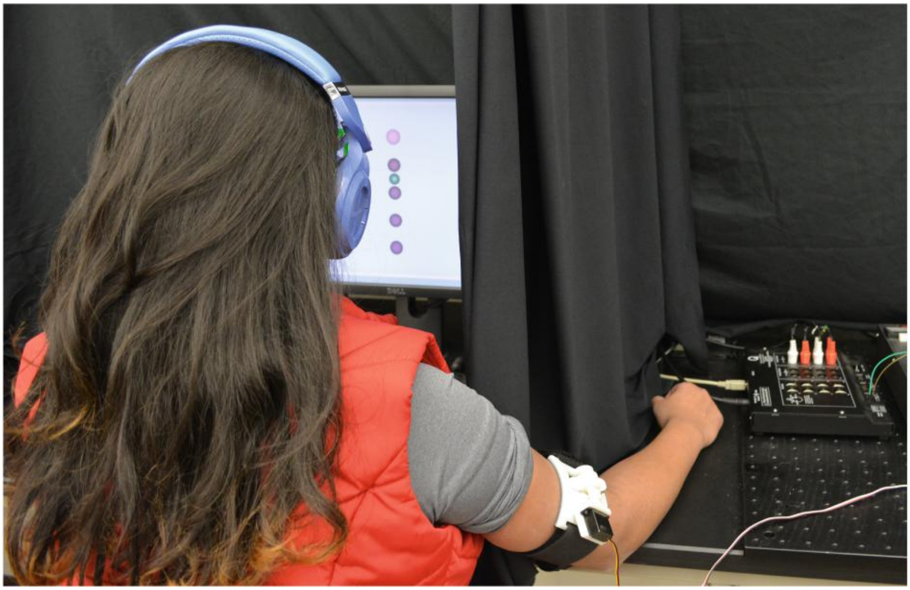


Fig. 2. The participant is seated at the bench facing the monitor, their right arm rests on the workbench with the rocker secured to the upper arm. Headphones provide pink noise to eliminate audio cues.

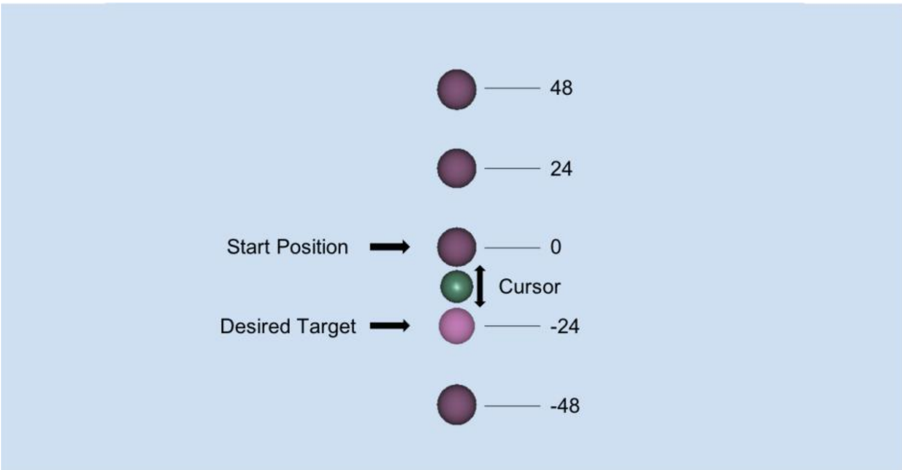


Fig. 3. The visualization for the perceptual task, the desired target blinks and the cursor is controlled using the keyboard.

3.3 Experimental Protocol

This navigation task was completed for the two rocker orientations, lateral and longitudinal, and each subject completed the task with both orientations in a single one-hour session. Trial times were determined by the subjects with no time limitations. To prevent possible training bias and effects of fatigue, half of the participants completed the task with the laterally oriented rocker first and the other half completed the longitudinally oriented rocker first.

The task comprised of three blocks: two training blocks and one assessment block. The blocks differed in the visibility of the cursor, which was included during training to create an association between the target positions on the screen and the stretch from the Rocker, and removed during the assessment to test their ability to reach the targets by relying solely on the rocker feedback. In the first training block, comprised of 20 trials, the cursor was present at all times during the trial. In the second training block, comprised of 60 trials, the cursor was not present until the participant confirmed they believed the target had been reached, when the cursor would display the final position. In the assessment block, comprised of 20 trials, the cursor was not visible at any point throughout the entire block. In all three blocks, an equal number of each increment and target were represented within each block.

4 Results

The differences in perception of the two rocker designs were quantified by the root mean squared error (RMSE) of the cursor position with respect to the desired target in the assessment phase, see Fig. 4. As well as comparing the overall performance of each rocker, the performance of the inner two targets were differentiated from that of the outer targets. The results show less error for the outer targets for the longitudinal oriented rocker, and less variability in the longitudinal case. For the lateral rocker, the mean RMSE was $9.3 \pm 4.7\,\%$ for the inner targets and $9.6 \pm 4.0\%$ for the outer targets. The longitudinal rocker had a mean RMSE of $9.2 \pm 2.0\%$ and $7.2 \pm 3.2\%$ for the inner and outer targets, respectively.

Statistical analyses were performed to identify performance differences in rocker orientations and between targets in the middle and toward the extremes of the workspace, as well as possible interactions between them. A 2×2 [Rocker (Lateral; Longitudinal) $\times$ Target (Inner; Outer)] repeated-measures ANOVA was used to assess the RMSE across conditions. The data was checked for sphericity deviations, though no Huynh-Feldt (HF) adjustments were required. The analysis showed a difference in RMSE between the rocker orientations, $F(1,\,22) = 5.40$, $p = .03$, $\eta^2 = 0.20$. A significant main effect was not present between the inner and outer targets, however the interaction approached significance, $F(1,\,22) = 3.41$, $p = .08$, $\eta^2 = 0.13$, causing the interaction to be investigated. The longitudinal rocker orientation did result in a significant difference between the inner and outer targets, $t(22) = 2.55$, $p = .018$, $d = 0.76$, though none was present in the lateral case.

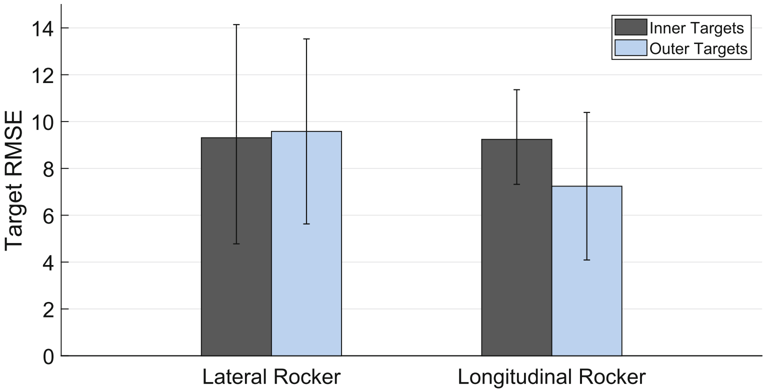


Fig. 4. The mean RMSE across all users for each experimental condition, error bars represent the RMSE standard deviation. The rocker orientation has a significant effect ($p = .03$), where the lateral rocker has higher errors than the longitudinal rocker. In the longitudinal case, outer targets are easier to discern than the inner targets ($p = .018$).

5 Discussion

In this work, impact of stretch direction in user perception for a target task is tested with the Rice Haptic Rocker. Lateral, or side to side, movement was compared to the more biologically accurate longitudinal, or up and down, stretch. Feedback provided with the longitudinal orientation of the rocker resulted significantly less positional errors compared to lateral cue orientation. This agrees with the initial hypothesis, that the presence of longitudinal stretch as a source of proprioceptive information makes the orientation more intuitive for the user compared to the lateral direction, though with a small effect size.

Other factors may also contribute to this result. By inspection, we observe more possible skin movement in the lateral direction compared to stretch along the length of the arm. Other factors could be related to the biology of the skin, in the mechanoreceptors or muscle and fat composition, requiring further research. Though the longitudinal direction has been shown to result in more accurate perception, because of the prominence of this mode in the human's existing proprioceptive system, the information may become confounded during dynamic tasks due to natural skin stretch existing in the arm. The haptic devices should be designed to be as inert as possible to external stimuli in the environment, and certainly during navigational and prosthetic applications the device will be used while the user is moving their arm. The impact of dynamic tasks and possibility of confounding the stretch cue should be investigated. In addition, the impact of the arm choice could be evaluated. One left-handed subject was included in this experiment, however the importance of arm dominance in feedback remains open.

The decrease in target error for the outer targets compared to the inner ones for the longitudinal rocker suggest some sort of nonlinear behavior. The torsional device used in [8] utilized an s-curve mapping in the device position to create larger increments near the neutral position and smaller ones toward the extrema in order to address this tendency. A similar s-curve mapping does not impact the target accuracy in [10], however this was using the lateral orientation of the rocker, which did not show a difference in errors between the targets in the presented work. This also could be related to the increased skin movement in the lateral direction, where insufficient skin tightness is achieved at the extrema of the lateral case for more sensitive change perceptions.

6 Conclusion

Skin stretch has been implemented in a variety of forms for haptic feedback to human users. In this experiment two stretch directions were compared using the Rice Haptic Rocker, in lateral and longitudinal directions on the upper arm. The longitudinal rocker produced smaller errors in a target task compared to the lateral orientation. For the longitudinal rocker, the outer targets had a smaller error compared to the inner targets, whereas the lateral rocker did not have a difference in the target location. These results could be due to at least two possible sources. One relates to the possible intuitiveness of the longitudinal direction from the use of skin stretch in joint motion for proprioceptive information. The second is the observed smaller amount of skin movement possible in the longitudinal direction, allowing smaller changes to be discerned in pre-stretched skin, perhaps not extensive enough in the lateral case. These results can assist in haptic device choice and design for applications relating to proprioceptive, navigation, compliance, and force feedback.

References

1. Akhtar, A., Nguyen, M., Wan, L., Boyce, B., Slade, P., Bretl, T.: Passive Mechanical Skin Stretch for Multiple Degree-of-Freedom Proprioception in a Hand Prosthesis. In: Auvray, M., Duriez, C. (eds.) EUROHAPTICS 2014. LNCS, vol. 8619, pp. 120–128. Springer, Heidelberg (2014). https://doi.org/10.1007/978-3-662-44196-1_16
2. Antfolk, C., Björkman, A., Frank, S.O., Sebelius, F., Lundborg, G., Rosen, B.: Sensory feedback from a prosthetic hand based on air-mediated pressure from the hand to the forearm skin. J. Rehabil. Med. **44**(8), 702–707 (2012)
3. Antfolk, C., D'Alonzo, M., Controzzi, M., Lundborg, G., Rosén, B., Sebelius, F., Cipriani, C.: Artificial redirection of sensation from prosthetic fingers to the phantom hand map on transradial amputees: vibrotactile versus mechanotactile sensory feedback. IEEE Trans. Neural Syst. Rehabil. Eng. **21**(1), 112–120 (2013)
4. Battaglia, E., Clark, J.P., Bianchi, M., Catalano, M.G., Bicchi, A., O'Malley, M.K.: The rice haptic rocker: skin stretch haptic feedback with the pisa/iit softhand. In: Proceedings of the IEEE World Haptics Conference (2017)
5. Blank, A., Brookshier, C.A., O'Malley, M.: Skin stretch feedback of gripper aperture for prosthetic hands in a grasp and lift task (work in progress). In: Proceedings of the IEEE World Haptics Conference (2015)

6. Casini, S., Morvidoni, M., Bianchi, M., Catalano, M., Grioli, G., Bicchi, A.: Design and realization of the cuff-clenching upper-limb force feedback wearable device for distributed mechano-tactile stimulation of normal and tangential skin forces. In: IEEE/RSJ International Conference on Intelligent Robots and Systems. pp. 1186–1193. IEEE (2015)
7. Caswell, N.A., Yardley, R.T., Montandon, M.N., Provancher, W.R.: Design of a forearm-mounted directional skin stretch device. In: Proceedings of the IEEE Haptics Symposium. pp. 365–370 (2012)
8. Chinello, F., Pacchierotti, C., Tsagarakis, N.G., Prattichizzo, D.: Design of a wearable skin stretch cutaneous device for the upper limb. In: Proceedings of the IEEE Haptics Symposium. pp. 14–20 (2016)
9. Cipriani, C.: DAlonzo, M., Carrozza, M.C.: A miniature vibrotactile sensory substitution device for multifingered hand prosthetics. IEEE Trans. Biomed. Eng. **59**(2), 400–408 (2012)
10. Clark, J.P., Kim, S.Y., O'Malley, M.K.: The rice haptic rocker: Altering the perception of skin stretch through mapping and geometric design. In: the Proceedings of IEEE Eurohaptics Conference (2018)
11. Collins, D.F., Refshauge, K.M., Todd, G., Gandevia, S.C.: Cutaneous receptors contribute to kinesthesia at the index finger, elbow, and knee. J. Neurophysiol. **94**(3), 1699–1706 (2005)
12. Edin, B.B., Johansson, N.: Skin strain patterns provide kinaesthetic information to the human central nervous system. The Journal of physiology **487**(1), 243–251 (1995)
13. Gleeson, B.T., Horschel, S.K., Provancher, W.R.: Communication of direction through lateral skin stretch at the fingertip. In: World Haptics 2009 - Third Joint EuroHaptics conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. pp. 172–177 (2009)
14. Guinan, A.L., Hornbaker, N.C., Montandon, M.N., Doxon, A.J., Provancher, W.R.: Back-to-back skin stretch feedback for communicating five degree-of-freedom direction cues. In: Proceedings of the IEEE World Haptics Conference. pp. 13–18 (2013)
15. Kim, K., Colgate, J.E., Santos-Munné, J.J., Makhlin, A., Peshkin, M.A.: On the design of miniature haptic devices for upper extremity prosthetics. IEEE/ASME Trans. Mechatron. **15**(1), 27–39 (2010)
16. Kuniyasu, Y., Sato, M., Fukushima, S., Kajimoto, H.: Transmission of forearm motion by tangential deformation of the skin. In: Proceedings of the 3rd Augmented Human International Conference. pp. 16:1–16:4. ACM (2012)
17. Meek, S.G., Jacobsen, S.C., Goulding, P.P.: Extended physiologic taction: design and evaluation of a proportional force feedback system. Journal of Rehabilitation Research & Development **26**(3), 53–62 (1989)
18. Minamizawa, K., Fukamachi, S., Kajimoto, H., Kawakami, N., Tachi, S.: Gravity grabber: Wearable haptic display to present virtual mass sensation. In: ACM SIGGRAPH Emerging Technologies. ACM (2007)
19. Okamura, A.: Methods for haptic feedback in teleoperated robotassisted surgery. Industrial Robot: the international journal of robotics research and application **31**(6), 499–508 (2004)
20. Schorr, S.B., Quek, Z.F., Romano, R.Y., Nisky, I., Provancher, W.R., Okamura, A.M.: Sensory substitution via cutaneous skin stretch feedback. In: 2013 IEEE International Conference on Robotics and Automation. pp. 2341–2346 (2013)
21. Stanley, A.A., Kuchenbecker, K.J.: Evaluation of tactile feedback methods for wrist rotation guidance. IEEE Trans. Haptics **5**(3), 240–251 (2012)

22. Sylvester, N.D., Provancher, W.R.: Effects of longitudinal skin stretch on the perception of friction. In: Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07). pp. 373–378 (2007)
23. Wheeler, J., Bark, K., Savall, J., Cutkosky, M.: Investigation of rotational skin stretch for proprioceptive feedback with application to myoelectric systems. IEEE Trans. Neural Syst. Rehabil. Eng. **18**(1), 58–66 (2010)
24. Yem, V., Otsuki, M., Kuzuoka, H.: Development of wearable outer-covering haptic display using ball effector for hand motion guidance. In: Kajimoto, H., Ando, H., Kyung, K.U. (eds.) Haptic Interaction: Perception, Devices and Applications, pp. 85–89. Springer Japan (2015)