자신의 피부를 누르는 힘을 입력으로 사용하는 인터페이스에서의 사용자 힘 입력 성능 이해

Understanding how Humans perform Pressure Input on the Body

김지성, Jiseong Kim*, 백두산, Dusan Baek**, Aditya Shekhar Nittala***, 이재연, Jaeyeon Lee****

요약˘피부는 다양한 변형이 가능해 다양한 상호작용이 가능한 인터페이스로 사용하기에 장점이 있다. 이전 연구에서 압력 입력이 광범위하게 연구되었지만, 피부를 사용한 맥락에서는 많이 이루어지지 않았다. 본 논문에서는 사람이 피부에 압력을 입력으로 사용할 때 어떻게 수행하는지 탐구한다. 우리는 두 가지 실험의 결과를 제시한다. 첫 번째 실험에서는 신체의 세 가지 위치에서 압력 입력을 수행할 때 편안하면서 가장 센 힘의 범위를 확인한다. 두 번째 실험에서는 목표물의 크기와 신체 위치가 압력 입력에 미치는 영향을 조사한다. 우리의 결과는 목표물의 크기가 신체 위치보다 더 큰 영향을 준다는 것을 보였다. 이는 우리의 고유감각이 신체 위치에 상관 없이 압력 수준을 정확하게 제어할 수 있게 한다는 것을 의미한다. 결과적으로 실험 결과는 신체 피부에서의 고유 감각적 압력 입력 설계에 있어 유용히 활용 될 것으로 기대한다.

Abstract˘˘The skin is a malleable, highly promising interface with diverse deformable interactions. While force input has been extensively studied in HCI literature, it has not been explored in the context of on-body input. This paper studies how humans perform force input on the body. We contribute results from two fundamental experiments: In the first experiment, we study the maximum and comfortable force ranges across three body locations for performing force input on the body. In the second experiment, we investigate the influence of the scale and location of the body. Our results indicate that the scale has a higher influence than the location of thebody. This indicates that our inherent proprioception allows us to control the force levels precisely regardless of the body location. Overall, results from our experiments inform the design of proprioceptive force input on the human skin.

핵심어: Force Input, 힘 입력: Wearable Interfaces, 착용형 인터페이스: Proprioception, 고유감각

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1. Inroduction

The human body offers a large and readily accessible surface for always available and eyes-free interaction. Most empirical investigations have focused on gestural interaction, elicitation studies, and mapping strategies. Even though human skin is a highly deformable and malleable surface that affords rich interactions, very limited work studies how humans perform such interactions. In this work, for the first time, we investigate the pressure input on the human skin. Using skin's soft and deformable properties and variations in elasticity in different body parts, we aim to understand how well humans can perform pressure input on the body.

Pressure input on the body fundamentally differs from the conventional pressure input on rigid (e.g., touchscreens) nor soft surfaces (e.g., silicone surfaces). First, when we interact with our bodies (e.g., apply pressure input on a button on the forearm), our inherent proprioception enables us to locate the button. When we perform the input, we feel tactile feedback in two different places: a) at the point where the interaction occurred (e.g., forearm) and b) at the fingertip, allowing us to localize and feel the input even when we are without sight. Such natural dual tactile feedback is absent when performing pressure input on conventional passive surfaces. Secondly, the feedback at the interaction location (e.g., forearm) differs across the body due to varying concentrations of mechanoreceptors in the body. Finally, the elasticity and softness vary across body locations (e.g., knuckles are more bony than the fleshy region on the forearm). Such intra-body differences highly influence the pressure input on the body.

To the best of our knowledge, we present the first series of experiments that meticulously and systematically study how humans can perform pressure input on the body. In summary, the contribution of this paper is as follows:

- Exploration of the comfort levels (i.e., Maximum and Comfortable Force, MCF) for applying pressure input in the body, and how do they differ between body locations

- Investigation of the user's performance (accuracy, number of crossings, and the completion time) of the pressure input in the body

2. Experiment

Overall, we conducted two experiments to understand the maximum comfort levels for applying pressure input and the performance of pressure input on the body.

2.1 Participants

We recruited 18 participants from a local university community (12m, 6f, 0d, all right-handed), aged 19 to 23 (mean=21,SD=2). All participants were paid.

2.2 Conditions

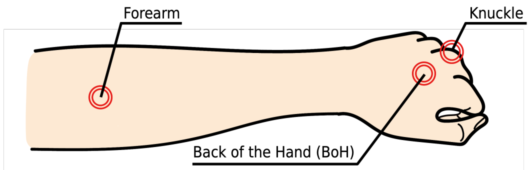

Fig. 1 Three Body Locations used in our study

We selected three Body Locations: Forearm, Back of the Hand (BoH), and Knuckle based on the elasticity and the usageof the body parts in the previous work on-skin interface. [1,2]

2.3 Experimental Setup

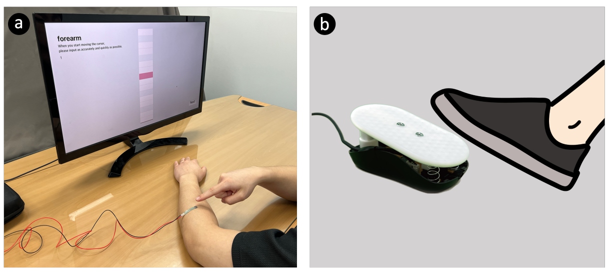

Fig. 2 (a) Experimental setup on the desk and (b) the foot pedal under the desk.

We used a Force Sensitive Resistor (FSR400, Interlink) to measure the force applied to each body location. As shown in Figure 1a we attatched FSR on the participant's body location with double-sided tape. Before measuring at each body location, we calibrated the FSR using a loadcell (TAL220) to remove the effects of different softness and elasticity of different body locations.

We used the foot pedal for confirmation for the

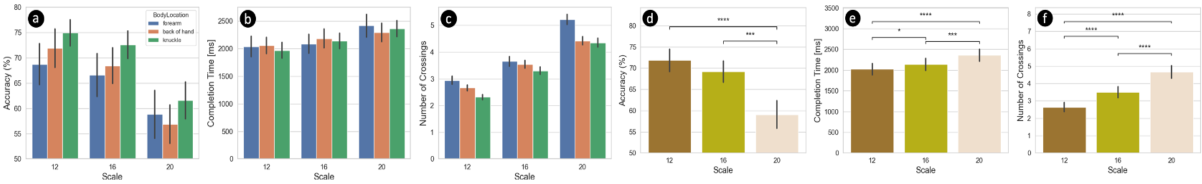

Fig. 3 Results of Experiment 2. (a-c) The Accuracy, CT, NC for each condition (d-f) the statistical comparisons

following reasons. Unlike previous studies that investigated pressure input on an external device [3], our study involved repeated pressure on Body Locations within a range of MCF. We wanted to avoid extending the force duration (e.g., dwelling), additional gestures on the skin (e.g., stroking), or additional devices on the skin to determine touch status (e.g., quick release). Therefore, we opted for an additional input device for confirmation. Given that the user's dominant hand and the forearm on the non-dominant side needed to maintain a stable posture, we utilized a foot pedal, as used in previous work when both hands are occupied [4].

2.4 Procedure

We asked participants to press the FSR sensor attached to their Body Location with their index finger with the maximum force they could sustain for 3 seconds without discomfort or pain. The screen showed the current level of force in a unit of N. The participants could save, reset, or re-create the value as many as they wanted. When measuring MCF, participants were allowed to look at the Body Location.

After measuring the MCF, We measured the participant's force input performance. When a trial started, participants were asked to control the cursor at the bottom by applying force using their dominant hand's index finger. When the cursor aligned with the target position, the participants submitted the answer by pressing the custom foot pedal modified from a mouse (Figure 2b). Our custom software logged the number of crossings (NC), completion time (CT), and the cursor's location at the moment of the trial.

3. Results

The average of MCF of all participants across all Body Locations was 18.44 (se: 0.17) N. For Forearm, BoH, and Knuckle,the average was 14.45 (se: 0.2) N, 22.59 (se: 0.4) N, and 18.27 (se: 0.23) N, respectively. Figure 4 shows each location'srange of measured MCF. The range was largest on Knuckle, and BoH and Forearm followed.

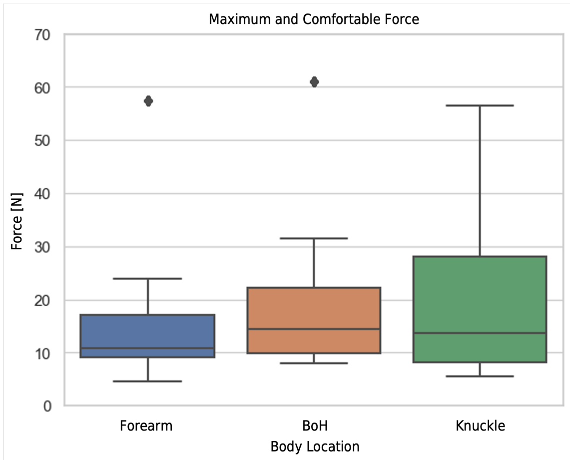

Fig. 4 The distribution measured MCF on three Body Locations

The overall accuracy was 66.7 (std: 16.57) %. Figure 3-(a) shows the average accuracy for Body Location and Scale. With a 2-way repeated-measures ANOVA (Body Location × Scale) the main effect of Scale on accuracy was statistically significant ($p < .005$), while Body Location was not statistically significant ($F_{2,34} = 1.501$, ns). And with a pairwise t-test, a significant difference was found in the pair of S12-S20 and S16-S20 as shown in Figure 3-(d).

The average of overall CT was 2,173 (std: 697) ms. Figure 3-(b) shows the average of CT for Body Location and Scale. We performed a2-way repeated-measures ANOVA (Body Location × Scale) on CT. As a result, themain effect of Scale on CT was statistically significant ($F_{2,34} = 25.165, p < .0001$), while the effect of Body Location was not statistically significant ($F_{2,34} = 0.77$, ns).

The average overall NC was 3.6 (std: 2.45) times. Figure 3-(c) shows the average of NC for Body Location and Scale. We performed a 2-way repeated-measures ANOVA (Body Location × Scale) on NC. As a result, the main effect of Scale was significant ($F_{2,34} = 43.32, p < .0001$) while the effect of Body Location was not significant ($F_{2,34} = 0.81$, ns).

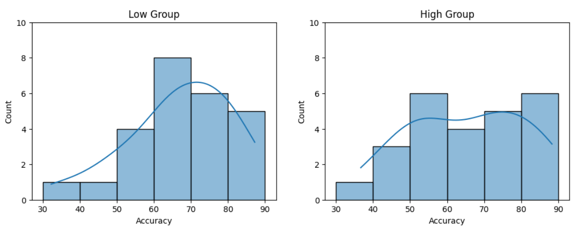

Fig. 5 Number of participants per accuracy interval in both groups, divided by the median of the MCF

Based on the median MCF of 11.195 N, we divided the groups into those that exceeded it and those that did not, and found no statistically significant difference in accuracy between the two groups (Figure 5). This means that there is no significant difference in accuracy between the two groups, suggesting that dividing the groups by the median MCF does not have a significant effect on accuracy.

4. Discussion

4.1 Comparison with Pressure Pain Thresholds

Our results align with prior work, which measured the pressure painthresholds in 29 body locations [5]. The Forearm typically has a lower pain threshold than compared to relativelybony regions: knuckles and the back of a hand. This aligns with prior literature, which has shown that soft tissue and nervy regions have lower levels of pressure pain thresholds when compared to bony and skeletal regions [5].

4.2 Comparison with Performance

Overall, the pressure input performance (Accuracy, CT, and NC) was hardly affected by Body Locations. At first, we selected the three body locations based on the elasticity and the usage of the body parts in the previous work on on-skin interfaces. However, as we proceeded, we learned that every body part is unique regarding its compliance, skin thickness, tactile sensitivity, curvature, and anatomical structures. Despite the differences, the pressure input performance was consistent.

5. Conclusion

In this study, we conducted two experiments to investigate how input performance varies depending on the different parts of the Body Location when using skin pressure as an input. In the first experiment, we investigated the range of forces that each person can apply to their body. In the second experiment, we investigated the visual selection performance of the force input based on Body Location. The results showed that the three different Body Locations had similar performance in terms of accuracy, CT, and NC. These results compare well with similar experiments conducted off-skin, indicating that on-skin force input is feasible for users.

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