Difference in Haptic Softness Estimation using Pressing and Pinching

Binyue Gao[a], Jiajia Yang[*], Yinghua Yu, Satoshi Takahashi, Yoshimichi Ejima, Jinglong Wu

Graduate School of Interdisciplinary Science and Engineering in Health Systems, Okayama University, Okayama, Japan

Abstract: People systematically use different touch strategies to perceive different object features. When interacting with a deformable object, human typically judge the softness by pressing the finger pad into the surface or pinching the object with the thumb and index finger. However, the link between touch strategy (e.g., pressing) and haptic softness perception needed to be explored. To ascertain how people's perceptions of softness are impacted by touch strategy, experiments on estimating softness were undertaken in the current study. Nineteen subjects were instructed to understand how to estimate the softness of a variety of haptic stimuli with varied elastic moduli by pressing and pinching. The results indicate that subjects were able to scale softness regardless of the touch strategy. However, the functions for scaling softness were affected by the touch strategy; the estimation of softness was greater with pinching. It suggests that the haptic perception of softness was affected by touch strategy. Additionally, the slopes of the functions were greater in the pressing group. This finding suggests that subjects in the pressing group showed better softness discrimination.

1 INTRODUCTION

Softness is one of the main dimensions of material properties in haptic perception. In daily life, we frequently interact with soft objects. When actively touching objects with the finger pad, we can judge, recognize, and discriminate objects by softness. For example, we judge the ripeness of fruit by its softness, and different softness also produce different affective sensations (Pasqualotto, 2020; Kitada, 2021). The previous study has shown that softness was regarded as the perceptual correlate of compliance which is defined as the degree of deformation brought by an applied force (Srinivasan, 1995; Friedman, 2008). Therefore, the deformation of the item and the related contact pressures enable the perception and differentiation of softness. The research is developing our understanding of the relationship between object deformation and contact forces. Such contact forces are thought to contribute to the perception of compliance. For example, reports have been made on the impacts of cutaneous contact area, skin deformation, and pressure distribution in space. In addition, a kinesthetic sense of joint angles beyond the skin contact area also augments our judgment of softness (LaMotte, 2000; Xu, 2019). These cutaneous and kinesthetic cues are recruited and integrated into multisensory signals. Moreover, these sensorimotor movements (Kaim, 2011) are fine-tuned by exploratory strategies, which the perception of softness. Therefore, the perception of softness is not only a process of sensory input and recognition but also simultaneously influenced by touch strategies. However, how touch strategy affects the haptic perception of softness is still unclear.

A touch strategy effectively extracts the relevant information regarding the object. An earlier study showed that there is a link between touch strategies and required knowledge about object properties and specific exploration procedures; people systematically use different touch strategies, so-called exploratory procedures (EPs). Pressure was used to encode softness (soft versus hard) (Lederman, 1987; Lederman, 1993). Thereby, an EP, regularly used in research related to this field, is better than other EPs at detecting the associated haptic property. However, a habitual EP can be achieved by more than one touch strategy. For example, the EP of pressure can be obtained by pressing or pinching with the fingers. Early research revealed that a pinch grip is a more natural motion for determining the ripeness of plum fruit than a single finger touch. However, it is still unknown that how the perceived magnitude of softness differs between these two different touch strategies.

In the present study, we examined the impact of touch strategy on the perception of haptic softness using the haptic stimuli of eleven distinct types of silicone rubber blocks with varying elastic moduli. Subjects were asked to touch the surface of each stimulus and then estimate the softness of the stimuli. Subjects used different touch strategy in a series of experiments. These touch strategies included: (1) subjects actively pressed each stimulus with the index finger of the right hand. (2) subjects actively pinched each stimulus with the index finger, middle finger and thumb of the right hand.

[a] p8t27rjy@s.okayama-u.ac.jp
[*] Corresponding author: yang@okayama-u.ac.jp

2 MATERIALS AND METHODS

2.1 Subjects

Nineteen healthy subjects (males = 15, female = 4; mean age = 25.8 years, SD = 4.0 years) subjects in this experiment. All subjects were right-handed and were naïve about the purpose of all experiments. In addition, all subjects gave informed consent to the procedure, which was approved by the local Medical Ethics Committee of Okayama University. The testing procedures were also reviewed and approved by the local Medical Ethics Committee of Okayama University.

2.2 Stimulus

Eleven specimens (Table 1) made of silicone rubber blocks ((TANAC Co., Ltd., Japan; Fig. 1) were conducted. Each rubber stimulus contained a plastic box (5 cm long by 5 cm wide by 1 cm deep) which was filled with silicone rubber.

Table 1 Elastic modulus and touch strategy

Touch strategy	Elastic modulus (kPa)
Press	5, 10, 20, 30, 40, 50, 60, 80, 110, 140, 170
Pinch	5, 10, 20, 30, 40, 50, 60, 80, 110, 140, 170

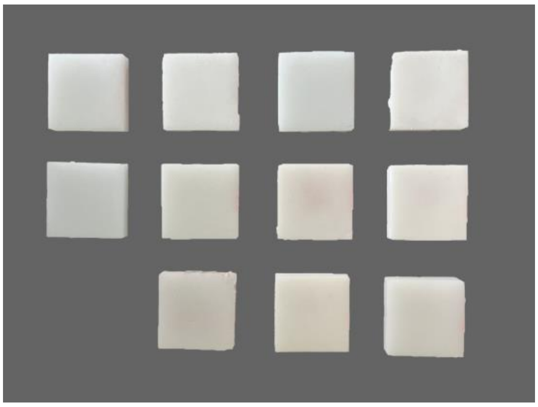

Figure 1. Stimuli. 11 types of stimuli made of silicone rubber were shown. Baby powder (corn starch) was applied on the stimuli's surface to minimize tackiness.

In order to allow subjects to directly touch the flat surface of the material, one or two sides of each box were open in the pressing and pinching task. Baby powder has been placed on each surface to reduce the stickiness of the rubber. The measurement for the elastic modulus of each stimulus was a sensor (SOFTGRAM, SHINKO DENSHI Co., Ltd., Tokyo, Japan).

2.3 Design

There were two within-subject variables in the experimental design: softness (11 types of silicone rubber blocks with different modulus of elasticity, 5~170 kPa) and touch strategy (pinch, press; Fig. 2). During the experiment, each subject finished a total of 220 trials. Due to avoid fatigue effects, we adopted two sessions on 2 different days. Moreover, a pseudorandom list of 110 trials was pre-set for each session, which interleaved the number of compliances. Each type of stimuli was presented 10 times in one experiment. Prior to the experiment, subjects took part in at least 22 practice trials to establish a general understanding of the stimulus range.

2.4 Peak Contact Force

To avoid the influence of peak contact force on the magnitude of softness estimation, in the pilot experiment, the subjects were asked to rate softness by actively pressing the stimulus with the right index finger under natural conditions. Each stimulus was mounted to a load cell (LCCU21N100, A&D Co., Ltd., Japan) which was used to measure contact force. The data sampling rate was 10 Hz. Under natural pressing conditions, the peak force is affected by compliance. The peak contact force when pressing on a highly compliant stimulus was lower than that when pressing on a minimally compliant stimulus, and the mean peak contact force range was 2.68 N. Depending on the elastic modulus of the stimulus, people strategically adjust movement parameters during pressing. The influence of stimulus compliance on the executed exploratory force has been described elsewhere (Kaim, 2011). The maximum mean peak contact force plus or minus one standard deviation was used to set peak contact force limits in the experimental trials exploring each stimulus. Therefore, we controlled the peak contact force of subjects to between 1.2 N and 5.8 N in the softness estimation experiment.

2.5 Experimental procedure

Subjects judged the softness of each specimen in a series of two tasks that varied in terms of the type of touch strategy subjects used (Fig. 2). Subjects were seated comfortably in a height-adjustable chair. The tactile stimulator was at waist level. Moreover, in order to prevent subjects from viewing the hand and the stimulus, their eyes were blindfolded prior to the experiment.

A

B

Figure 2. Subjects scaled softness using two-touch strategies. (A) Subjects actively pressed each specimen with the index finger of the right hand. Each specimen was mounted to a load cell that was used to measure compressional force. (B) Subjects actively pinched each specimen with the index finger, middle finger, and thumb of the right hand.

2.6 Paradigms: Magnitude estimation task

The method of subjective magnitude estimation was adopted in the experiment. At the beginning of the trial, the subjects placed their right hand in the designated position. After a sound cue, the subjects started exploring the stimulus twice with the indicated touch strategy. After finishing the exploration of the target stimuli, subjects were instructed to report the softness magnitude of the target stimuli. In addition, the peak pressure training was also conducted prior to the experiment, which requires a peak force ranged from 1.2 and 5.8 N for each subject. Under the condition of press strategy, subjects were asked to explore each stimulus using a similar force. Then, they needed to indicate the softness of the presented stimulus by rating from 1 to 100, with higher number being softer. Before the formal experiment was conducted, subjects were required to be subject to 22 practice trials in which the exploration process was engaged, due to give the subjects a general understanding of the presented stimuli range.

2.7 Data and Analysis

Repeated-measures analysis of variance (ANOVA) was conducted to valuate the difference of softness. If Mauchly's test of sphericity was violated, the greenhouse corrections were conducted. If there was a significant interaction between two factors (softness, touch strategy), post hoc analysis was conducted using the paired-sample test with a Bonferroni correction. The significant level was at $p < 0.05$. The R version 4.2.1 with the "bruceR" package was used for all statistical analysis.

3 RESULTS

The individual data for all nineteen subjects were plotted and are presented in Fig. 3. The magnitude estimates of softness by each subject increased monotonically as a function of compliance regardless of whether the specimen was pressed or pinched (Fig. 3a, b). There were significant main effects on the softness estimation for the touch strategy ($F(1, 18)=23.207$, $p<0.001$) and the elastic modulus of the stimulus ($F(3.084, 55.517)=374.724$, $p<0.001$). There was no significant interaction ($F(3.068, 55.217)=2.22$, $p=0.095$) in the experiment. The two-way repeated-measures ANOVAs indicated that the touch strategy affected the softness estimation; when the elastic modulus was 5 kPa or 20 kPa, the touch strategy had no effect on softness estimation. In addition, the log-linear slopes of the functions were -0.4481 and -0.4541 for pinching and pressing, respectively (Fig. 3c).

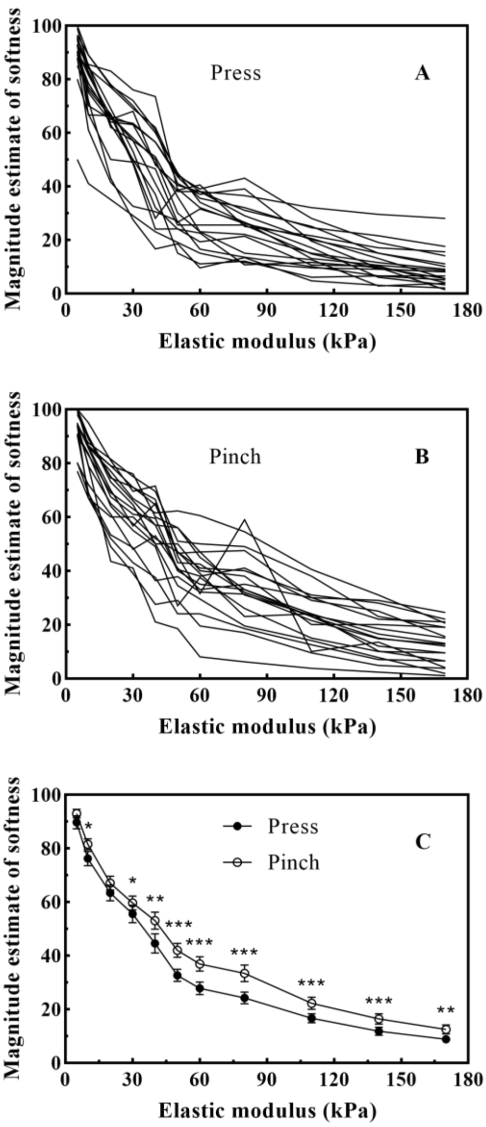

Figure 3. Perceived softness as a function of the elastic modulus of each specimen actively pressed or pinched with the finger pad. (A) While pressing the specimens, individual subjects obtained magnitude estimates of softness. (B) While pinching the specimens, individual subjects obtained magnitude estimates of softness. (C) Estimation of the average magnitude of softness obtained by pressing and pinching the specimen. (*p < 0.05, **p < 0.01, and ***p < 0.001).

4 DISCUSSION

The results demonstrated that softness estimation was significantly affected by the touch strategy. Whether through active pressing with a finger or pinching with two fingers, the softness estimation decreased with the elastic modulus of the stimulus. However, softness ratings for pressing were different from those for pinching. The stimuli were judged to be less soft in the pressing task than in the pinched tasks. Consequently, the log-linear slopes of the softness scaling functions were steeper in the tasks that involved indentation with a finger. These results extend previously obtained results on softness scaling, in which subjects were able to estimate object compliance by active or passive direct contact with the finger pad, or by indirect contact with the tool.

The haptic exploration procedure is determined by the properties of the objects that the haptic system chooses to process, including perceptually and discrimination. Thus, it has been speculated that exploratory movements are executed in a way that "optimizes" the computation of relevant properties (Klatzky, 1999). However, based on the two different touch strategies under exploratory procedural pressure, the perception of softness also shows different results. In this study, pressing allowed greater discrimination of softness, whereas pinching produced a greater perception of softness. This may be due to differences in movement parameters that affect the human perception of softness. Several studies have shown that subjects perform the same EP with different motor parameters, depending on the stimulus characteristics or the perceived goal of the explored movement. The number of fingers used in the perception of softness has been shown to affect performance. Some study has compared how well humans can discern compliances based on whether they are pressed with their index finger or pinched between their thumb and index finger (Freyberger, 2006). When compared to the group of subjects who pinched the stimuli between their thumb and index finger, the group that just used their index finger to press the stimuli had better discriminative performance, according to the differential sensitivities (d’). In another study that more fingers can lead to better compliance discrimination according to the exact conditions.

Taken together, the number of fingers can influence softness perception. However, the perceived difference in softness between the two different touch strategies cannot be explained by the finger contact area alone.

In the pressing task, subjects were instructed to use a specified peak force to press the stimulus surface, and in the pinching task, they were instructed to pinch the stimuli with equal force. However, we do not know the rate of force change (force/time) during object exploration in the two touch strategies. Prior research has shown that subjects will adapt their approach velocities, depending on the expected softness (Friedman, 2008). This suggests that the rate of force change is likely to be used as a movement parameter to adjust our perception of softness to improve performance.

Under stereotypical EP pressure, there are differences in the perception of softness between different tactile strategies, which cannot be explained by a single movement parameter. This is because under EP pressure, the softness of an object can be judged from the relation between the applied forces and the sensed object deformation. The EP pressure makes it possible for people to make accurate judgments about softness since it produces important sensory signals as well as redundant tactile and kinesthetic information (Srinivasan, 1995).

In the present study, we only focused on the impact of touch strategy on softness estimation. However, different touch strategies generate different movement parameters, and how these cues, such as the rate of force change, affect the perception of softness is not clear. In addition, it is not clear how humans integrate the touch and kinaeshetic signals to perceive softness. These are interesting questions for future research.

5 CONCLUSION

The present study investigated the differences between two different touch strategies, pressing and pinching, in a softness perception task. Although both different touch strategies were good at estimating softness, the press strategy was better at discriminating, and the press yielded higher estimates of softness. This suggests that touch policies can be adapted for specific purposes to improve performance.

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