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Exploring the Influence of Surface Roughness and Compliance on Softness Perception among Adult Women

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--***ABSTRACT***--

The Enhancing the realism of tactile experiences in laparoscopic surgery through the development of tactile displays is a crucial endeavor. A primary challenge in designing such displays revolves around grasping how touch perception varies across different material properties. This project endeavors to tackle this challenge by exploring how the interplay of material properties influences the perception of softness.

The project seeks to investigate how the interplay of surface roughness and compliance influences the perception of softness using a psychophysical experiment. The experiment involved nine stimuli representing three distinct compliances, each with three varying patterns of surface roughness. Findings from the experiment reveal that compliance significantly influences softness perception, both during finger pressure and sliding movements. Furthermore, surface roughness also exerts an impact on softness perception. Notably, significant interactions between compliance, roughness, and individual subjects contribute to the perception of softness.

This project is an essential step towards understanding interactions between compliance and other material properties which affect perception of softness and how this understanding can be applied to the medical field, especially laparoscope surgery.

KEYWORDS;-*Human perception, softness, compliance, roughness, stickiness, tactile displays*

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I. INTRODUCTION

In the realm of product design and consumer experience, the perception of softness plays a pivotal role in shaping preferences, satisfaction, and ultimately, purchasing decisions. The tactile qualities of materials, ranging from textiles to foams, significantly influence how individuals interact with and perceive various products. Understanding the intricate relationship between material properties and perceived softness is essential for designers, manufacturers, and marketers striving to create compelling and appealing products (Abreiak, 2014, Abreiak and et al, 2016).

Numerous studies examine the tactile perception of material characteristics like texture, flexibility, temperature, and friction. They delve into psychophysical functions that link physical attributes to perception, including thresholds for discrimination. Additionally, there's discussion on the neural mechanisms underlying these sensations and exploring methods to artificially induce such tactile experiences in haptic displays. Furthermore, researchers investigate how the perception of these material properties interacts with one another (Bilhassan and et al, 2020; Lieber and Bensmaia, 2022; Sakamoto and Watanabe, 2017).

Tactual perception encompasses various sensations tied to the sense of touch, including pressure, vibration, temperature, and the body's position in space through proprioception and kinesthetic movement. Softness and flexibility perception are particularly crucial for distinguishing between healthy and unhealthy tissues, particularly in laparoscopic surgery. Compared to traditional open surgery, laparoscopic procedures offer advantages such as reduced tissue trauma, less post-operative discomfort, shorter recovery periods, decreased hospital stays, and lower healthcare costs. Figure 1.1 illustrates a tactile perception system (Abreiak and et al. 2017).

The tactile experience plays a vital role in executing grasping and manipulation tasks, interacting with the environment, and facilitating communication between humans and machines in various domains like virtual reality and immersive experiences. Over time, many technologies have been suggested to replicate the sensation of touch. These applications range from providing sensory feedback for amputees, enhancing precision and skill in operating teleoperated robots, aiding visually impaired individuals, to serving as interfaces in virtual environments and gaming (Pyoand et al, 2021).

The absence of tactile feedback places significant demands on surgeons' skills and experience. They must adapt to this lack of sensory input, which is time-consuming and poses risks to patient safety. Tactile display technology has revolutionized human-computer interaction by enabling users to perceive and manipulate digital information through the sense of touch. Among various advancements, the tactile display of softness on fingertips represents a significant milestone. This technology allows users to feel virtual textures and surfaces with remarkable realism, enhancing immersion in virtual environments and augmenting sensory experiences. By simulating the sensation of softness directly on the fingertips, users can interact with digital content in a more intuitive and natural manner. This innovation has profound implications across numerous fields, including virtual reality, gaming, medical simulation, and rehabilitation (Frediani & Carpi, 2020).

II. Methodology

The objective of this research is to investigate how surface roughness influences the perception of softness. To accomplish this goal, we employed magnitude estimation to gauge participants' softness ratings of materials. Magnitude estimation is a scaling technique commonly utilized in psychophysics to quantify the intensity of a sensation experienced by an individual. Participants were then instructed to assess the softness of each texture through two methods: running their finger across it and pressing their finger into it.

Participants

Thirty naïve female volunteers with an age range of 20 - 25 years participated in the experiment. Handedness questionnaire (Briggs and Nebes (1975)) was used to identify the dominant hand. Participants were asked to tick a suitable choice on the handedness questionnaire from a five-point scale. Participants took a few minutes to complete the handedness questionnaire. Table 1 shows scores for the scale point and total scores, and which total scores were interpreted to measure the strength of handedness for each participant. Participants were asked to press or slide the sample, dependent on the instruction given by the researcher, using the index finger of their dominant hands to assess the compliance of samples. The participants could not see the stimulus to remove any influence from the shape and surface differences between the stimuli. None of the subjects reported any neurological or physical injury that affected sensitivity of the index fingers of both hands.

Score point	score
Always right	+2
Usually right	+1
No preference	0
Always right	-1
Usually right	-2

Total scores	Dominant hand
24 to -9	Left handed
-8 to +8	No preference
+24 to +9	Right hande

Table 1 Scores for the scale point for determining dominant hand

Stimuli

Nine stimuli with three different levels of compliance and three different levels of roughness in all combinationswere made. Stimuli were produced in dimensions of (8cm×8 cm×20 cm). These were made from sponge of different compliances (Figure 1 and 2).

Fig. 1 Stimulus made from textile to show different levels of roughness

Fig 2 Stimulus made from different sponges to show different levels of compliance

Design

There were 9 conditions, corresponding to the combinations of two independent variables: compliance (soft, neutral and hard) and roughness (smooth, neutral and rough) and the pressing and sliding conditions. The order of stimuli was randomized for each participant. The design used was balanced ANOVA. The pressing and sliding conditions were counterbalanced. The experimental approach used was to develop a two-factor factorial run-in randomized block design. In this approach, two factors were used: compliance and roughness. Minitab 17 statistical software was used to design a two-factor factorial run-in randomized block design.

From that, spreadsheets were compiled to calculate the results for each participant. In order to avoid any effects from the behavior of the participants on treatments, the counterbalanced design was used in this experiment. The experiment had two conditions (A = pressing with softness and B = sliding with softness), these conditions required two orders (Beierholm. 2007) in which these can occur. Participants were divided into two groups, each having an equal number of participants, which meant 15 participants were in each group. It meant all participants were treated with a different order of conditions (with pressing first, followed by sliding and sliding first followed by pressing).

Procedure

Each participant was given a brief outline of what the experiment would involve. An instruction sheet was presented to each participant, which explained how the experiment should be performed to ensure participants understood what they should do.

Participants took part in this study individually, so they did not influence each other in their responses. Twenty-seven runs were used during the experiment for each participant. The magnitude estimation procedure had been chosen as the most appropriate method under two experimental conditions pressing and sliding to evaluate the perception of softness. All participants during their experiment were provided with a reference stimulus. This stimulus acted as a reference and was assigned a value of 10 by the experimenter and it had a middle value for compliance.

Before starting the experiment, in order to help participants understand magnitude estimation, they were given an explanatory sheet (Appendix A.2). This sheet, which was developed to allow participants to understand the concept of magnitude scaling, was based on an example exercise described by Lodge citied in (Abreiak and et al. 2017). In this exercise, participants were asked to assign a value which was a positive, non-zero integer, decimal, or fraction of first "reference line". Participants were asked to assign how much longer or shorter the remaining lines were compared to the reference line. The longer a line seemed to be, the larger the number they should assign it. The shorter a line seemed to be, the smaller the number they should assign it compared with the reference line. All participants were asked if they understand exercise and their answers were checked to make sure they were acceptable. None of participants had to withdraw because they could not understand the procedure.

A pilot experiment was carried out to ensure that instructions were understandable and clear. This pilot experiment was conducted by the researchers and their supervisor. After the pilot experiment, slight adjustments were made to the instructions so that they would be more understandable.

The participant was seated in front of a box on one side of a table and the researcher was on the other side of the table. The participant was asked to rate 27 stimuli compared to a reference stimulus. To avoid the participants from seeing the stimuli, a box was dropped half way across the breadth of the table. The stimuli were placed behind the box in the same place. The participant was presented with the test and reference stimuli which were placed in front of the participant, the reference stimuli was placed on the participant's right hand side while the texture the participants were asked to evaluate was placed on their left hand side (as shown in Fig. 3). Participants were asked to press the textures; then they were asked to slide their fingers over the surface. They were instructed to use the same index finger in both cases. The participants had to rate one surface at a time. the participant put their hand through the box to touch the test stimulus and reference, and they can go back to indicate how many times softer the test stimulus on their left compared to reference stimulus by assigning a proportional value to the test stimulus. The researchers wrote down this value in "test stimulus" on a sheet. The softer they thought the stimulus on the right was, the smaller the value they should assign to it compared to the value of the reference stimulus. The less soft they thought it was, the greater the value they should assign it. So, for example if they thought a test stimulus is twice as soft as the reference one, they would assign it a value that is twice as small as value of reference stimulus, while should they have felt that the stimulus is half as soft as the reference one, they would give it a value twice as great as the value of the reference.

Before starting, each participant wiped his or her fingertips with hand hygiene wipes to clean off any sebum or dust. The stimuli set were also cleaned with a mild surface cleaner (non- bleach, no taint and no odour) to ensure constant stimuli intensity. Participants were allowed to rest at any point during the experiment if necessary. After each condition, each participant was allowed to rest for as long as they needed: rest times ranged from 0-5 minutes. The experiment lasted for approximately 20 minutes and the full study was performed within 3 weeks.

Fig. 3 The box used in the perception of softness psychophysical experiment

III. RESULT

Balanced ANOVA was conducted using Minitab 16 statistical software to explore relations between the human tactile perception and roughness and to find whether there is interaction between two factors within each condition; this section reviews the results for each condition in turn.

Pressing Condition

Table 2 shows the geometric mean and standard deviation for perception of softness under pressing conditions. Figure 4 shows the raw data, the x-axis and y-axis represent the compliance level and perception of softness for different roughness levels. This figure compares the perception of softness for different compliance in different surface roughness. The rating of softness increases with increasing compliance level and increasing surface roughness.

Stimulus	Geometric Mean	Standard Deviation	Compliance Level	Roughness Level
1	10.73	3.72	Hard	Smooth
2	10.37	3.94	Soft	Rough
3	11.91	3.77	Neutral	Neutral
4	7.998	4.25	Hard	Rough
5	9.90	3.92	Soft	Smooth
6	11.17	4.38	Soft	Neutral
7	10.49	3.85	Neutral	Rough
8	8.89	3.46	Neutral	Smooth
9	10.40	3.96	Hard	Neutral

Table 2 Geometric Means and Standard Deviation for Perception of Softness Through Pressing Condition.

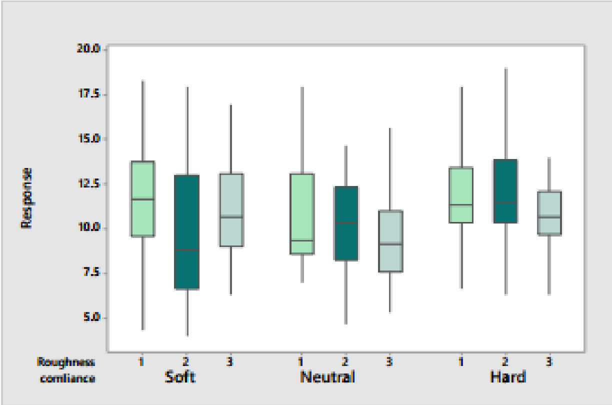

Fig. 4 The Boxplot for Data (Pressing Condition) for Roughness, Smooth (1), Neutral (2), Rough (3).

Balanced ANOVA was carried out with the normalized magnitude estimates of perceived softness as the dependent variable, and compliance and roughness as independent variables. Table 3 shows the main effects of compliance, roughness, the interaction between compliance and roughness and the subjects.

Source	DF	F Calculated	P-Value	Effect
Compliance	2	8.63	0.000	Sig.
Roughness	2	1.92	0.149	Not Sig.
Subjects	29	5.64	0.000	Sig.
Interaction between Compliance and Roughness	4	2.74	0.027	Sig.

Table 3 The main effects of compliance, roughness, thesubjects, the interaction between compliance and roughness using (α= 0.05)

All effects are reported as significant except the main effect of roughness. There was a significant main effect of compliance on the perception of softness. This indicated that changing the compliance level will change the perception of softness. At $p > 0.05$ there was not significant main effect of roughness. There was a significant interaction effect between the level of compliance and the level of roughness used. This means that changing the level of roughness and compliance will affect the perception of softness. The block (subjects) significantly affected the perception of softness so it can't be removed. The results showed that perception of softness was affected by compliance for the pressing condition. That the previous results are affected (Metzger and Drawing, 2019, 2020; and Adams and et al, 2016). It varies with studies and research (Freidan and Carpi, 2020; Yang and et al, 2017).

Sliding Condition

Table 4 shows the geometric mean and standard deviation for perception of softness under sliding condition. The raw data, the x-axis and y-axis represent the compliance level and perception of softness for different roughness levels was shown in Figure 5. This figure compares the perception of softness for different compliance in different surface roughness. The rating of softness increases with increasing compliance level and increasing surface roughness.

Stimulus	Geometric Mean	Standard Deviation	Compliance Level	Roughness Level
1	4.82	4.27	Hard	Smooth
2	11.96	4.07	Soft	Rough
3	9.12	3.52	Neutral	Neutral
4	11.46	3.67	Hard	Rough
5	5.11	4.81	Soft	Smooth
6	8.16	3.98	Soft	Neutral
7	11.69	3.83	Neutral	Rough
8	5.05	4.49	Neutral	Smooth
9	8.15	3.77	Hard	Neutral

Table 4 Mean and standard deviation for perception of softness through sliding condition.

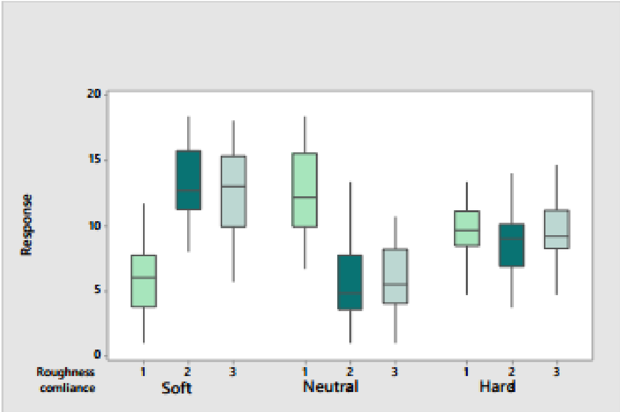

Fig. 5 The Boxplot for Data (Sliding Condition) for Roughness, Smooth (1), Neutral (2), Rough (3).

Balanced ANOVA was carried out with the normalized magnitude estimates of perceived softness as the dependent variable, and compliance and roughness as independent variables. Table 5 shows the main effects of compliance, roughness, the interaction between compliance and roughness and the subjects.

Source	DF	F Calculated	P-Value	Effect
Compliance	2	5.84	0.003	Sig.
Roughness	2	0.59	0.554	Not Sig.
Subjects	29	1.71	0.017	Sig.
Interaction between Compliance and Roughness	4	12.88	0.000	Sig.

Table 5 The main effects of compliance, roughness, the subjects, the interaction between compliance and roughness using (α= 0.05)

From the tests of subject effects, there was a significant main effect of compliance on the perception of softness. Otherwise, there was also not significant main effect of level of roughness on the perception of softness. There was a significant interaction between the level of compliance and the level of roughness used, the block (subjects) significantly affects the perception of softness so it cannot be removed. The results showed that perception of softness was affected by compliance for the sliding condition that the previous results are affected (Metzger and Drawing, 2019, 2020; and Adams and et al, 2016). It varies with studies and research (Freidan and Carpi, 2020; Yang and et al, 2017).

There is a significant difference between the levels of compliance. This means that participants could distinguish between different compliances for all surface roughness.

Comparing between our results study (female participants) and the pervious results study (male participants) [12],[11]

Pressing condition

There is significant difference in the results after comparing with pervious results as shown in Table 6. T-test was used to find the main different between studies as shown in Table 7.

	Source	DF	F Calculated	P-Value	Effect
Male	Compliance	2	1175.73	0.003	Sig.
	Roughness	2	27.68	0.000	Sig.
	Subjects	29	3.14	0.000	Sig.
	Interaction between Compliance and Roughness	4	12.65	0.000	Sig.
Female	Compliance	2	8.63	0.000	Sig.
	Roughness	2	1.92	0.149	Not Sig.
	Subjects	29	5.64	0.000	Sig.
	Interaction between Compliance and Roughness	4	2.74	0.027	Sig.

Table 6 Comparison between ANOVA Results

	DF	T-test	P-value	Effect
Male	177	0	0.321	Not Sig.
Female				

Table 7 Two-Sample T-Test and CI: female; male

Sliding condition

There is significant difference in the results after comparing with pervious results as shown in Table 8. T-test was used to find the main different between studies as shown in Table 9.

	Source	DF	F Calculated	P-Value	Effect
Male	Compliance	2	30.98	0.003	Sig.
	Roughness	2	1531	0.000	Sig.
	Subjects	29	4.14	0.000	Sig.
	Interaction between Compliance and Roughness	4	3.19	0.000	Sig.
Female	Compliance	2	5.84	0.003	Sig.
	Roughness	2	0.59	0.554	Not Sig.
	Subjects	29	1.71	0.017	Sig.
	Interaction between Compliance and Roughness	4	12.88	0.000	Sig.

Table 8 Comparison between ANOVA Results

	DF	T-test	P-value	Effect
Male	162	0	0.505	Not Sig.
Female				

Table 9 Two-Sample T-Test and CI: female; male

IV. DISCUSSION AND CONCLUSIONS

The aim of this experiment was to establish whether the interaction between surface roughness and compliance could influence the perception of softness. Across the two conditions tested (pressing and sliding), there was a strong outcome that interaction between roughness and compliance affects the perception of softness. In this section the main findings are summarized and their implications discussed.

The main result of the experiment was that the compliance × roughness interaction had significant effect on perceived softness; this was true for both pressing and sliding conditions.

This may be because the big difference between compliance levels and small frictional forces between the finger tips and the stimulus. The amount of deformation that fingers undergo during pressing may be one reason, because it depends on the contact force and how stiff the material is compared to a finger.

This experiment also shows that participants were able to distinguish between the compliance for each roughness level. Perception of softness might depend on the objective compliance of the stimuli and people could discriminate softness easily through active touch. Our results are in agreement, since the compliance was largely determined by the influence of other material properties, The comparison of these results with previous findings (Abreiak and et al, 2017, Bilhassan and et al, 2020) shows very different judgments on the relationship between perceived softness and physical hardness, as well as there's a significant effect between perception of softness and interaction between compliance and roughness surface.

The findings indicated that the perception of softness was influenced by compliance during the pressing phase. This discovery aligns with earlier research conducted by Shirado and Maeno (2005), Bergmann Tiest and Kappers (2006), Abreiak (2014), Bergmann Tiest and Kappers (2009), Tsuchimi et al. (2012), and Abreiak et al. (2017).

The current results contrast with prior studies by Petrie et al. (2004), Abreiak (2014), and Abreiak et al. (2017), where they found no significant correlation between the perception of surface smoothness and the physical hardness of samples, nor were there significant interactions with other variables like surface shape. Furthermore, our findings align with Shirado and Maeno (2005), who demonstrated the impact of elasticity on tactile perception across various materials.

Yet, these findings appear to align with several documented studies (Bergmann Tiest& Kappers, 2006; Shao et al., 2009; Chen et al., 2009), indicating that the perception of softness is associated with other material attributes such as compliance. It appears that roughness and softness are perceived distinctly; roughness can be discerned by sliding a finger across the surface, while softness is assessed by pressing the finger onto the surface (Pagnanelli and et al, 2023) .

These results carry important implications for the design of tactile displays, especially concerning the representation of softness. The outcomes of this study could guide developers in determining the methods for creating tactile sensations and how to effectively convey this information to surgeons' fingertips.

Therefore, the tactile display was constructed. As evidenced by the analysis, there was a high mean perception of softness observed in instances of low roughness. The perception of softness is contingent upon factors such as the manner in which stimuli are touched, the increase in contact area with contact force, the pressure exerted over the contact area, and the force applied to press the stimuli, as indicated by Bergmann Tiest (2010), Johnson et al. (2000), Friedman et al. (2008), and Pasqualotto et al. (2020).

V. CONCLUSION

A study was carried out to investigate the impact of the interaction between compliance and surface roughness on the perception of softness. The findings revealed that this interaction significantly influences perceived softness under both sliding and pressing conditions, suggesting that compliance and surface roughness exerted distinct effects on participants' ratings.

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