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RESEARCH ARTICLE-MECHANICAL ENGINEERING

Psychophysics Experiment to Check the Temperature Impacts Over Human Fingertips for the Application of Textural Applications in Haptics Technology

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Abstract

Psychophysical methods in haptic technology help in comparative study and eventually be a data set to achieve realism over skin sensation. Textural based haptic applications are widely developed using tactile displays over human fingertips. The tactile displays work on open-loop admittance feedback system and are controlled with flexible parameters by ignoring the impact of noise or disturbance variables. Human skin undergoes various noise factors like temperature, humidity, sweat, and influence of alternative senses. This paper presents the newly adopted method of psychophysics to study the influence of environmental conditions over perceiving textural surfaces. The paper adopts the detection mode of psychophysics which uses perception time as an output parameter for understanding perception memory of the human skin. We have recorded the period of the perception in three environmental conditions over human subjects under a single blindfold method to study the behaviour of human skin at fingertips. The perception time of stimulus is analysed with arithmetic average roughness value (R_a) to understand the tolerance factor required during tactile based textural applications. The proposed method is simple to structure and improves in creating the dataset required to consider the noise factor for an open-loop admission feedback system.

Keywords Psychophysics · Textural applications · Haptics technology · Perception

1 Introduction

Haptic is a study that explains the philosophical expressions behind the sense of touch. Touch has been keen observatory research in understanding the behaviour of skin and its interaction with external stimuli. Skin is the brain's only direct medium which understands the physical conditions around the human body. The study of the adoption of skin interacting with the physical world is termed as Haptics. The implementation of the tools to the haptic study based on touch as feedback is referred to as Haptics technology [1, 2]. Haptics technology is an interdisciplinary study of psychological behaviour occurring in humans or animals for perceptions generated through physical stimulus and interfaced with electro-mechanical constraints for controlling and operational responses for field resources [3].

In general, Haptics technology is an application-based research, focusing on touch as a major feedback platform. The skin has a variety of taxonomy when generalized to make a perceptive memory exist between brain and external stimuli. As shown in Fig. 1, the skin is classified into rapidly adoptive and slowly adoptive receptors which are below the dermis to handle the interaction through neurons. These receptors work based on the depth and intensity of the frequency that has been applied over the skin [5, 6]. Multiple tools have been designed to achieve perception through real or virtual interactions, such as vibrotactile, electro-tactile, physical pins, and other combinational display or actuators [7, 8]. These displays produce physical expression over the skin (such as stiffness, friction, pressure, coetaneous pain, or vibrations), which engages intensity and frequency-based skin receptions. An intuition is generated between neurons and cerebral cortex after an interaction with external stimuli.

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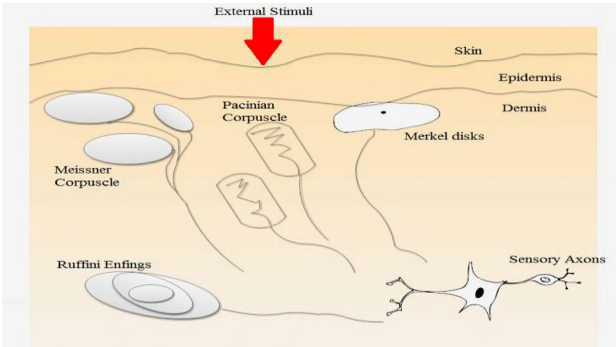

Fig. 1 Skin and mechanoreceptors connected with sensory axon [4]

The intuitions generated gradually get adopted by the perceptual memory, which is a general learning process for animals in evolution [8, 9]. So far, skin research has gained multiple responses over multidimensional geometry, bringing out many hidden receptors in the skin. These receptor plays a critical role in the technical study of haptic-based applications since they are categorized based on applied frequency and depth of penetration. Apart from psychological classifications, haptics technology focuses on generating feedback systems for multidimensional applications such as teleoperated surgical robotics, field robotics, home appliances, machine vibrations feedbacks, and automobile feedback systems [10].

The haptic based systems relay on open-loop and close-loop parameters of impedance and admittance. The kinaesthetic based haptic application works on close-loop feedback system and tactile displays work on open-loop feedback systems. The close-loop system has precise feedback grain factors to create realism, while open-loop system in haptics depends on pre-assumption data by ignoring the noise factor. Human skin undergoes various noise factors like temperature, humidity, sweat and few times influenced by other human senses. To address noise, each feedback system is taken into modelling based on the system design parameters. The close-loop system in haptic applications uses force feedback and position encoder feedback for accounting the noise (for example force dimension delta series and universal haptic teleoperated interfaces). Whereas tactile based haptic applications are designed using open-loop admittance, so the noise is taken from skin's perception in real work. To study, the real time skin perception psychophysics experiments are adopted [11, 12].

Psychophysical experiments are fundamental approach to understand human sense organs. The psychophysical parameters also define the time and intensity the perception memory is going to remember [13–15]. The psychophysical experiments on vision and audibility are quite explored, and well-defined due to its commercial value and are found as a limitation in skin-based realism experiments. Psychophysical experiments help in understanding skin behaviour based on geographical differences and genetical observations. Human beings experience multiple stimulus contacts, thus remembering only a few, which create magnitudes impression [16]. Psychophysical experiments can be conducted based on three models, magnitude, matching, and detection methods. Magnitude-based psychophysical experimental models are studied for intensity levels between two stimuli based on the extent generated by the theoretical values. The magnitude models are used for vision-based psychophysics experiments after the perceived magnitude to intensity of the stimuli. Matching based psychophysical models are like magnitude model, where series of stimulus is provided to identify and compare based on intensity levels. The method is widely used for audio–visual psychophysics experiments. The third model is detection, which follows yes or no status with single blind folded setup for perception. The detection-based psychophysics method generates dataset of perception over time and studied over descriptive statistics. The psychophysical experiment in the paper discusses the perception of skin using detection-based psychophysics model due to its flexibility in forced choices for perception [13, 15]. The impressions of forced choices are used in textural contact, physical density, geometrical distribution, and emotional cognitive patterns [6]. Hairy skin is less sensitive to perception due to very low neural density compared to non-hairy skin, and tactile applications adopt experiments largely over human fingertips due to its dexterity. The experimental setup discussed is a cost-effective and time-saving technique that can help haptics researchers adopt finger-related textural applications regardless of the tool selection. The method helps to understand noise factor in the units of time and sampled to haptic open-loop admittance systems.

The experiment data set generated can be fed to any optimization algorithm for multiple sublayers of data for better perception in open-loop admittance system [17]. The human perception and response time are necessary for cutaneous feedback systems to compare the realism existing while interacting with virtual or physical medium [18].

2 Experimentation

Psychophysical experiments were conducted using materials that are commonly used and are part of the day-to-day activities. Materials sediment certain behaviour of roughness, hence causing humans to remember them from attentive memory to perceptive memory [19–21]. The experimental process was conducted in two stages: firstly, to identify the correct test bench setup and secondly to perform psychophysics experiments. The stimulus was unchanged for both the stages.

2.1 Stimulus Classification

Materials such as glass, brick, cloth, metal, silicon rubber, wood, paper, rough plastic, cardboard, and rough paper were selected and classified. The average roughness values were ranging from 0.025 to 4.569 µm for all the ten stimuli. The roughness of the stimulus was measured using coherence correlation interferometry non-contact roughness measurement. The restriction of using 0.025–4.569 µm is because of the mechanical properties of that skin exhibit. Any roughness values lower than 0.025 µm were sensed similar and any material has roughness higher than 4.569–5 µm, the skin recognizes it as a structural dimension rather than a 2Dimensional rough profile [6]. This kind of behaviour of skin is due to visco-elastic property. The stress–strain ratio of in-vitro text explains that load greater than 0.25 Mpa causes a huge deformation exhibiting a drastic stretch in the skin and thus recognizing the roughness values greater than 5 µm as a geometrical structure [22].

2.2 Method

2.2.1 Test Bench Selection

Pre experimental analysis was performed for test bench selection. The experiment was carried out using a detection mode of psychophysics or human binary format by recognition yes–no condition. Six participants were asked to identify stimulus over three types of platforms. The participants were asked to use the active using hand for detection over test bench and second hand was used for perception. The experiment was repeated for each participant across all five fingers and under three different temperature conditions. All participants were blindfolded with random material recognition. Test bench selection was considered by doing repeatability tests over Just Noticeable Difference (JND). The method of identifying JND varies based on the human senses assumed and in the case of the experiment detection mode is followed. In detection method, the human binary answers are considered like a simple yes–no condition. The stimulus was shaped to 4 cm^2 surface area with variable thickness. The board in circular shape has a radius of 13 cm as shown in Fig. 2.

The choice of the board is based on the repeatability achieved for individual platforms. The repeatability in this experiment is selected based on the ratio of just noticeable difference (JND) values, which were taken in terms of seconds (Blindfolded) as shown in Table 1. Three shapes of setup boards were used—rectangular, hexagonal, and circle.

The experiment was carried out using six male participants based on age and fingertip scales (ridges and whorls), ageing from 25 to 30 years. The setup bench was designed with 10 stimuli, each with a uniform size. To create the test bench, various base platforms such as rectangular, hexagonal, square, and circle were set up. The circular platform for the stimulus was satisfying the reachable-repeatable ratio close to 54%. In Table 1, the data explain the reachability to repeatability in seconds.

The board was placed 50 cm away from the human chest, which is again the mean value of the entire arm length of the participants. The setup is shown in Fig. 2.

$$\text{The repeatability calculation}: \; R_X = \sum(\text{JND}) / \sum T_X \tag{1}$$

where X is A, B, and C for ten stimuli

$$\sigma(X) = \pm\frac{\left(T_{\max} - T_{\min}\right)}{2} \tag{2}$$

where R repeatability, JND Just Noticeable Difference, TX = time taken in each board, $\sigma(X)$ = tolerance factor.

From Eq. (1), we obtain the repeatability. The greater the repeatability better the perception memory for

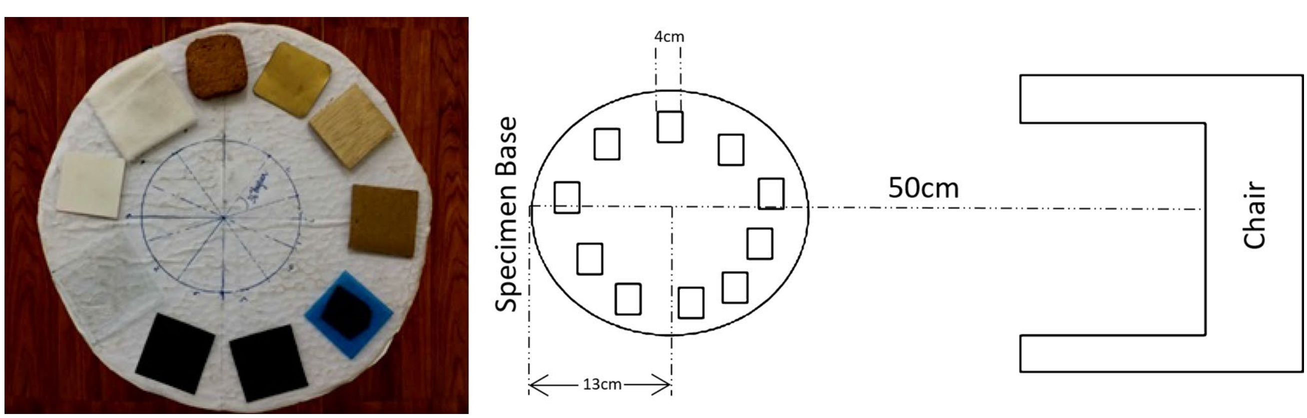

Fig. 2 Board setup and experiment orientation

Table 1 Expressions of JND and time of detection of each setup

Sl. no	Material	Roughness (μm) (Ra)	JND (s)	T_A (Square)	T_B (Hexagon)	T_C (Circle)
1	Glass	0.025	0.42	12.54	10.87	6.45
2	Rubber	0.041	0.24	14.83	9.57	7.24
3	Metal	0.197	0.52	18.56	16.34	9.11
4	Paper	0.387	0.47	16.58	14.07	7.29
5	Wood	0.501	0.45	13.54	11.25	6.72
6	Rough paper	1.231	0.57	15.22	16.31	9.06
7	Cardboard	1.952	0.51	17.41	9.33	8.64
8	Rough plastic	2.175	0.46	15.02	7.67	8.17
9	Cloth	4.0802	0.36	13.57	10.54	6.41
10	Brick	4.569	0.25	13.12	14.62	9.08

remembering the texture. Using Eqs. (1) and (2), the repeatability and tolerance values are taken.

$$R_A = 0.028; \quad \sigma(A) = \pm 6.02$$

$$R_B = 0.035; \quad \sigma(B) = \pm 8.65$$

$$R_C = 0.054; \quad \sigma(C) = \pm 2.7$$

The observation in Table 1, does not explain the percentage of correctness. A descriptive statistic was performed over data set to check the best fit platform for psychophysics. The repeatability and tolerance are the two conditions noted from Table 1. Repeatability can be calculated by taking total outcomes to actual perceived outcome (Eq. 1). The tolerance factor (Eq. 2) is assumed to be as mean value of overall perceived time, as mean value ideally fits in the intermediate range. The circular platform R_C gave better repeatability with the lowest tolerance factor, which in turn helped to judge the circle to be the best shape for the psychophysical experiment. All the experiments were conducted to check the responses of the fingers over the textural surface under three environmental conditions. The design of the board was placed 50 cm away from the participants, calculated using the average value of the full length of the arm of the participants.

2.2.2 Psychophysics Experiment

The participants were given test bench and under blindfold condition the detection mode of psychophysics was performed. To investigate the perception behaviour of fingertips, the environmental conditions were accounted. The three environmental conditions are with respect to temperature only. Firstly, a room temperature condition, second an air-conditioned/controlled condition of 20–24 °C (this temperature is referred to be the comfort zone for human beings for any working condition) and an open environmental condition. The experiments were conducted in Chennai, a city in India. The experimental data set is with respect to tropical climate. The temperature in open environment conditions from 10 am to 1 pm is 35–40 °C in May, where the open environment condition was conducted. The room temperature was 28–30 °C, measured using a digital temperature sensor. Factors like humidity and moisture are expected to influence the perception time. The three conditions over physical stimulus were conducted with a blindfold technique for six fingers (five fingers plus index finger for the second time) for textural recognition through detection method or human binary perception (yes–no).

Blindfold is a term coined from clinical research, namely single-blinded and double-blinded experiments. In the single-blinded experiment, the doctor knows the outcomes, but the patient is unaware of the drug and the procedure. In the double-blinded experiment, the doctor and the patient are unaware of the outcomes from the drugs or the procedure. Similarly, in this psychophysical experiment, the participants are blindfolded to sense the perception and understand the behaviour of fingertips over roughness perceived. Time is the only output data taken with roughness values of each stimulus under three environmental conditions. Before each experiment, the participants were asked to dip the fingers in hot water for opening the skin pores.

3 Results

The experimental results are studied over 10 stimulus each under three environmental condition over six human participants generating a data set of 1080. The data were observed and studied using descriptive statistic. The minimum and maximum value for each stimulus is taken to observe the overall time taken for recognition. While experimenting, participants often confuse between the roughness of close values. Those results were not considered as the participants were asked to repeat the same stimuli by shuffling the location of the materials.

3.1 Controlled Condition (20–24 °C)

This condition is considered as the most comfortable temperature range for people to sit and work for maximum time with less fatigue both physically and mentally. From Table 2, the higher roughness values (< 4 µm) and lower roughness values (0.25 µm >) values were detected with very less standard deviation when compared with intermediate values of other stimuli. But in overall criteria, all the stimulus had a standard deviation lesser than 2 s. The minimum value attended in this stimulus was 0.34 s by 4.803 µm roughness value and maximum value of 9.33 s by 1.952 µm stimuli as shown in Table 2.

3.2 Open Environment

In this condition, the temperature factor was discrete, unlike the first condition. In this condition, factors like heat, humidity, sweat, and noise were the most crucial factors. A standard deviation from 17 to 33 s was observed over the roughness values. The maximum time taken to detect stimuli was 70 s, whereas minimum time taken to detect was 1 s at higher roughness values, i.e., cloth. The total time taken to detect one roughness is greater than 1000 s except for brick and cloth as shown in Table 3.

3.3 Closed Room

In this condition, lower roughness values below 0.5 µm and higher roughness values greater than 4 µm gives better deviation and mean when compared to the intermediate roughness values as shown in Table 4. In this condition, the minimum time duration is observed at 0.13 s for higher roughness values and the maximum time duration is 44.7 s for the intermediate roughness at 1.952 µm.

In all the three conditions, the minimum time duration was for fifth and sixth iteration, and maximum time was seen in the first and second iteration. The intermediate stimulus in all the three conditions was seen in higher time duration

Table 2 Descriptive statistics of controlled condition (20–24 °C)

Material	Roughness µm (Ra)	*N* (total)	Mean (s)	Standard deviation	Sum	Minimum	Median	Maximum
Glass	0.025	36	1.47194	1.47244	52.99	0.51	0.76	6.43
Rubber	0.041	36	4.17667	1.70289	150.36	2.07	3.66	8.36
Metal	0.197	36	4.07972	1.77842	146.87	1.34	3.63	8.91
Paper	0.387	36	4.31139	1.88950	155.21	1.48	4.25	7.41
Wood	0.501	36	3.71750	2.00928	133.83	0.74	3.61	7.91
Rough paper	1.231	36	5.42806	1.70725	195.41	2.61	5.10	9.31
Cardboard	1.952	36	4.18194	1.65650	150.55	1.36	3.91	9.33
Rough plastic	2.175	36	4.25278	1.66346	153.1	1.46	3.96	7.75
Cloth	4.569	36	1.16778	1.09620	42.04	0.51	0.74	5.33
Brick	4.803	36	1.87722	1.67465	67.58	0.34	1.18	6.48

Table 3 Descriptive statistics of open environment

Material	Roughness µm (Ra)	*N* (Total)	Mean (s)	Standard deviation (s)	Sum (s)	Minimum (s)	Median (s)	Maximum (s)
Glass	0.025	36	33.175	8.56768	1194.3	10.01	34.75	48.31
Rubber	0.041	36	30.50194	12.18416	1098.07	12.81	29.43	57.21
Metal	0.197	36	30.40889	11.30938	1094.72	11.59	29.295	69.46
Paper	0.387	36	28.97333	11.52495	1043.04	11.17	28.645	68.08
Wood	0.501	36	30.84389	10.08039	1110.38	15.41	29.54	59.17
Rough paper	1.231	36	30.56778	8.54338	1100.44	17.39	30.21	50.45
Cardboard	1.952	36	30.63028	10.49832	1102.69	11.29	28.405	51.26
Rough plastic	2.175	36	30.71778	8.09082	1105.84	18.47	29.675	49.2
Cloth	4.569	36	17.78389	14.85501	640.22	1.01	14.445	57.82
Brick	4.803	36	27.63139	7.24244	994.73	13.67	27.675	42.12

Table 4 Descriptive statistics of closed room (room temperature)

Material	Roughness µm (Ra)	*N* (Total)	Mean (s)	Standard deviation (s)	Sum (s)	Minimum (s)	Median (s)	Maximum (s)
Glass	0.025	36	4.69333	4.15629	168.96	0.17	4.070	19.62
Rubber	0.041	36	5.93583	5.61011	213.69	0.54	3.495	20.87
Metal	0.197	36	7.20667	4.19538	259.44	1.33	6.620	20.61
Paper	0.387	36	7.52889	5.33337	271.04	1.17	5.825	25.65
Wood	0.501	36	8.19750	7.58580	295.11	0.24	5.415	30.12
Rough paper	1.231	36	6.91306	6.47140	248.87	0.65	5.650	32.75
Cardboard	1.952	36	7.40278	9.50411	266.50	0.17	4.225	44.70
Rough plastic	2.175	36	5.65000	4.03463	203.40	0.75	4.280	15.50
Cloth	4.569	36	2.09500	2.90625	75.42	0.13	0.725	14.30
Brick	4.803	36	2.84611	4.48361	102.46	0.13	1.110	21.76

through the experiment for all the fingers, but did reduce while performing fifth and sixth iteration. Roughness values lesser than 0.197 µm and greater than 4 µm gave similar time results in perception for all the conditions by about 97% closeness.

4 Discussion

In 20–24 °C, controlled condition the response of the fingers over the textural surfaces was within a few seconds. The higher surface roughness materials like brick and cloth had quick responses compared to other materials. In-room temperature, Fig. 2, a uniform response was observed and increasing the time duration to twice as 20–24 °C. The mean is slightly rising from lower roughness values to 1.231 and tend to decrease till the 4.802. The rise and fall of the mean explain the behaviour of the human fingertips and the adaptation towards each stimulus.

At open environmental conditions, maximum time duration was found overall the stimulus, but again a linear perception level was observed by looking at the mean of the individual stimulus. In open environmental conditions irrespective of environmental factors, which usually influences in perceiving the stimuli through sweat or heat, tend to show uniform detection time throughout.

The fingertips response can be seen in Figs. 3, 4, and 5. The response graphs leave a trend explaining the increase in time duration for each environmental condition in correlation with time vs roughness. As all the participants were undergoing six trails (Five fingers + Index finger repetition), the average time taken in perception also reduced. The air-conditioned room with 20–24 °C was very quick in perception, but was not consistent throughout the process, while looking at the mean value. Whereas the room temperature and open environment conditions have performed close to consistency concerning mean. This purely shows that human

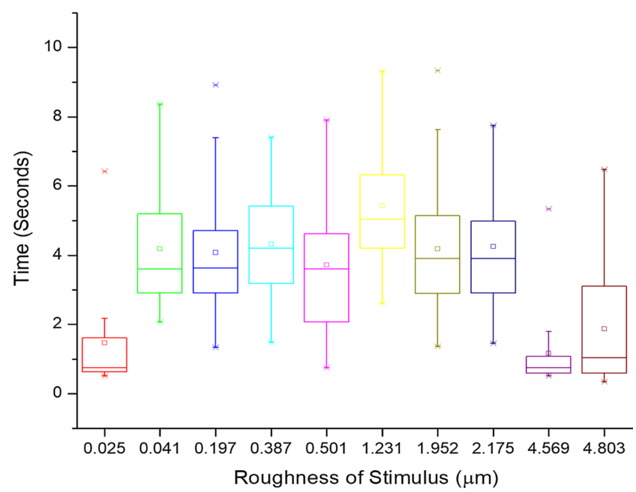

Fig. 3 Response graph of controlled condition (20–24 °C)

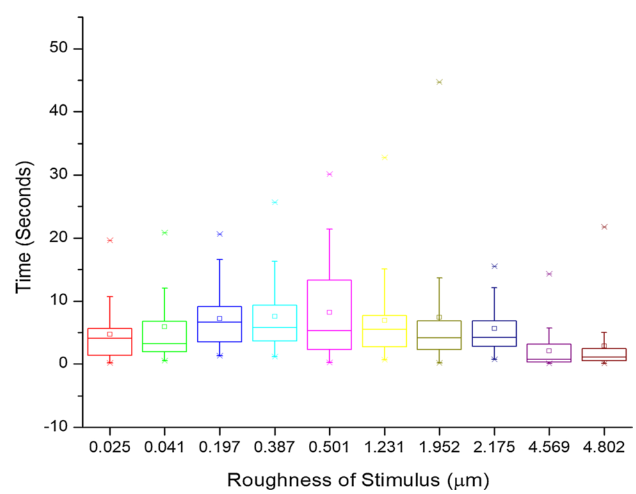

Fig. 4 Response graph of room temperature (close room)

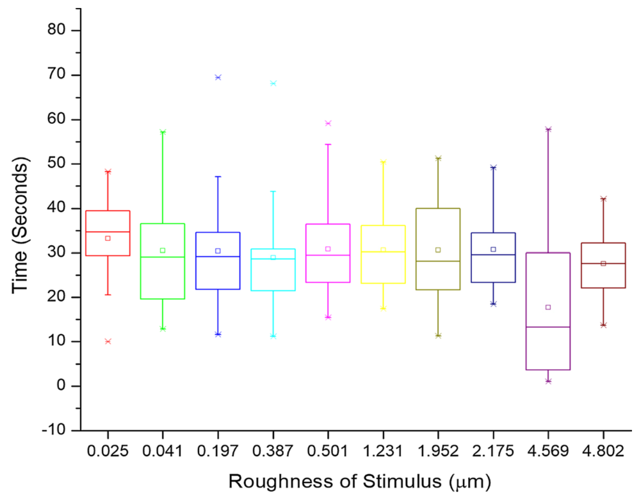

Fig. 5 Response graph of open environment condition

behaviour and adaptation towards general geographical conditions do impact the textural feedback perception, which might disturb the concept of common haptic feedback systems. In all the conditions, one common point was observed, that is, the reduction of perception time kept on reducing after multiple trails, and this was observed over all the participants. The results also show that the rapidly adoptive receptor cells in the skin are quite unresponsive towards higher temperature values, which are usually involved in low-pressure skin contacts. Higher temperatures were helpful with slow adoptive receptors which keeps consistency in mean as seen in all the responsive graphs. Materials like brick, wood and glass gave a uniform response rate for fingertips perception. This states that human skin perception is restricted towards limited adoptive nature towards textural surfaces and needs to be segregated based on neural density for future inspection on textural applications. Due to the uncertainty in the perception of skin with temperature conditions (also other environmental factors), the researchers require to adopt new materials to interface the tactile displays.

5 Conclusion

The setup is cost-effective and time reducing in the field of haptic perception in textural applications. Haptic feedback uses vibrotactile, electromagnetic, ultrasonic, and electrotactile for textural perception applications, where for a particular roughness to be sensed from a stimulus should always match a common trial and error frequency for training the user [23, 24]. Certain methods are also adopted to use an anaesthetic way to judge human finger behaviour for perception and learning [25]. Thus, implying the difficulties to face in mapping human perception training over any virtual reality tasks or applications. The experimental setup in the paper reflects a similar perceptive of training human finger with larger time gives better results or implementing new materials that can bring complete isolation from external stimuli and noise factors. The experimental results reduce time in matching the frequency and intensity parameters if used as a basic experimental approach for formulating the parameters for any textural applications in Haptics technology. The paperwork will be further analysed and used as a comparison study using various tactile displays for gravity independent feedback towards textural applications. The two-dimensional approach of textural perception can also be used and monitored for commercial applications, and its comparative analysis [4].

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