# Tactile Perception of Passenger Vehicle Interior Polymer Surfaces: An Investigation using Fingertip Blind Observations and Friction Properties

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Abstract: There is a growing demand for "soft-touch" materials for use in, for instance, interior components of cars, and similar goods that are subject to hand-held contact. The current study focused on touch-feel perception (human fingertip - blind observer) and friction properties in an air-conditioned room, with an ambient temperature of  $20\pm1^{\circ}$ C and a relative humidity of greater than  $40\pm5\%$  RH. The conclusion leads to within the sight observers, 60% contributed with regard to the tactile sensory input, and 40% contributed with regard to the visual sensory input. Therefore, both attributes contributed to the final decision, with a 99.7% ( $\pm3\sigma$ ) level of confidence. On the other hand, within the blind observers, 60% contributed with regard to the tactile sensory input, and 0.0% contributed with regard to the visual sensory input, with a 60% ( $\pm1\sigma$ ) level of confidence. Moreover, there is a strong correlation between the pattern for both genders (blind observers) to prefer S1 material as the smoothest one. Also, there is a strong correlation between the pattern for both genders (sight observers) to prefer S5 for both and S9 for women as the smoothest material and the preferred one. Furthermore, there is a strong correlation between sight<sub>(Women)</sub> observers and surface roughness,  $R_{ar}$  On the other hand, there is no correlation between blind<sub>(Women, Men)</sub> observers and surface roughness,  $R_{ar}$  results.

Keywords: Perception; Fingertip; Surface Roughness; Polymer; Friction Properties.

#### **1.Introduction**

There is a great deal more to a product's functionality than purely technical engineering features. As the engineering quality of various products is no longer a distinctive selling point but rather a minimum requirement, consumers are seeking emotionally interesting goods. Moreover, welldesigned, attractive sensory products generate a strong customer-product relationship, which can most definitely extend a product's lifetime decisively as an early replacement is prevented, thus reducing energy and material consumption, a core factor in eco-design and sustainability strategies [1]-[3]. Materials selection is a mature discipline where physical parameters such as surface roughness, elastic friction modulus, shear strength and many others are used to predictors of how a material will perform in technical applications [4].

Over the years, studies of psychophysical research have been carried out in the field of vision, gustatory and auditory perception. However, only little has been conducted with regard to the tactile, missing the opportunity to work on the second vital sense after vision, when it comes to product perception and probably the dominating one during the production stage [5]. Particularly, in cars, customers spend the majority of their contact time inside the cars, the choice of materials used in the interior can have a considerable impact on the customer's decision/behavior and sensory engagement. This has led to so-called effective engineering, the study of "human-product" interaction at a "soft-touch" subject level, which was pioneered as Kasei Engineering in Japan [3].

#### 1.1. Process of Perception (Touch and Vision)

Humans are extremely adept at recognizing common objects by touch-vision [6]. The process of tactile perception is structured into three levels: (1) biophysical interaction level, (2) neuron sensory level and (3) perception evaluation level [2]. Figure 1 shows the process of the touch-feel perception (e.g., finger touch).





#### **1.1.1. Biophysical Interaction Level**

As humans touch surfaces with their fingers, their complicated motions lead to the physical interfacial interaction between the epidermis skin layer (about 0.1 - 0.2 mm in depth) and a surface. Not only the surface properties such as texture and strength affect this interaction, but also the variation of skin conditions due to a series of physiological mechanisms related to the skin, e.g., blood circulation, sebum/sweat lubrication. Physically, the interfacial could lead to changes of strain/stress or thermal state at the dermis layer.

#### 1.1.2. Neural Sensory Level

Those changes are sensed as tactile stimuli by numerous mechano-receptors or thermos-receptors. Meanwhile, other visual stimuli in association with a surface color or reflectivity may also be sensed. The tactile stimuli are transferred through the nervous system and reach the brain. The sensory receptors for touch and proprioception are complex in structure. However, the simple organization is that of a neuron that has an ending, endings responsible for mechanic-electric transduction. As soon as the mechanical stimulus is transduced into an electrical impulse, the neuron conveys this information very rapidly to the spinal cord and then to the brain. Information arising from the mechanoreceptors of the body and face goes to specific regions within the brain that interpret the signals regarding tactile perceptions. The cortical regions devoted to this function have many independent representations of the body surface.

#### **1.1.3. Perceptual Evaluation Level**

As the tactile stimuli reach the brain, where psychophysical judgments are made and combined they are also later compared to the memory of previous experience to create effective judgment. These decisions are finally expressed upon the understanding of a complex semantic context at the evaluation stage.

# 2. Methods

## **2.1 Material Properties**

A range of different materials was used as the stimuli in this study. Nine polymers (LyondellBasell, Basell, German) with different topographies and identical dimensions of a length of  $10 \times 10 \times 2$  mm were chosen for this experiment as shown in Table 1. The density, tensile stress and flexural modulus of all the material samples were obtained using this Lyondell Basell database. The pattern polymer surfaces are made of five types of materials as listed in Table 1 and the entire pattern surfaces are heat embossed with four different pattern types: "Yukon", "Stripple 005", "N111" and "N127". The materials were either typical of automotive interiors or of household items so that the haptic familiarity to the participants has to be assumed. The pattern type of "N111" is observed with bumpy grains while the "Stripple 005" pattern has glossy surfaces and dimples with similar grain size. Also, coarse patterns such as "N127" and "Yukon" are observed with a skin-like pattern and glossy spherical bumps, respectively.

It should be noted that, the previously published data in [7], for "sight observers" male and female differences have been investigated for a variety of quantitative and qualitative sensory tests. The authors concluded that  $S5_{(Men, Women)}$  and  $S9_{(Women)}$  represented the smoothest materials and the preferred one amongst all nine samples. Also, it concludes that the surface roughness,  $R_a$ , results confirmed that the smoothest surface was S9 among all nine samples. As an important part of the development of psycho-physical materials, this paper involved looking at single perceptual variables, i.e., touch-feel perception for "blind people"

(women and men), friction properties (coefficient of friction and friction force), followed by SEM surface topography. This is the approach taken in this paper for touch perception.

<b>Fable 1:</b> List of materials	(LyondellBasell,	, Basell, German)
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No.	Material Name	Density (g/cm3)	Tensile Stress (MPa)	Flexural Modulu s (MPa)
S1	Softell TKG 300N	1.09	36	2500
S2	Softell TKG 259N (Yukon)	1.05	31	1700
<b>S</b> 3	Softell TKG 259N (Stripple 005)			
<b>S</b> 4	Hostacom EYC 136N (Yukon)	1.00	22.5	2000
S5	Hostacom EYC 136N ( <i>Stripple 005</i> )			
S6	Softell TKS 209N (N111)	0.91	8	85
<b>S</b> 7	Softell TKS 209N (N127)			
<b>S</b> 8	Hostacom ERC 342N ( <i>N111</i> )	0.97	21	1600
<b>S</b> 9	Hostacom ERC 342N (N127)			

# 2.2. Participants

Participants in this study were in the region of Makkah, KSA and only nine materials S1 to S9 had to be evaluated as listed in Table 1. It is recommended that some 40 control healthy participants are acquired to gain the relevant results time-effectively and use the conclusions for larger studies later on. Twenty men (18-28 years: Mean = 21.5 years,  $\pm$ SD = 2.97 years) and twenty women (18-29 years: Mean = 20.7 years,  $\pm$ SD = 3.31 years) took part in this investigation (from Al-Noor School for blind observers). All participants were native Saudi and naïve as regards the aim of the study. No bias was given for or against anyone as a result of their gender, ethnicity or nationality. Indeed, a small reimbursement was given to each participant after the evaluation session for their time and effort.

# 2.3. Design

Two groups of participants were tested in separate sessions, one male group of twenty and one female group of twenty so that each participant was rated three times for each sample. So, in all each participant performed 135 tests in total.

## 2.4. Testing Protocol

The intention of the research was to examine the tactile perception of a variety of materials with the intention of revealing how well human perception, the "*blind observer*" related to the psychophysical property data. Upon arrival, all participants had read to them the information sheet before taking part in the experiment. Upon agreeing to participate in the study, all participants were free to withdraw at any point. Participants were then compensated for their time and effort. Before each testing session, the participants washed their hands and forearms using a mild, soapy solution (5% triethanolamine lauryl sulphate in water) and then dried these

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areas using a cotton towel before being seated at the station. The time between washing and the first test was approximately 5-10 minutes. Testing took place in an airconditioned room, with an ambient temperature of 20±1°C and a relative humidity of 40±5% RH. Bear in mind, a small difference in environmental conditions was observed due to the fact that different laboratories were required for the different groups. Participants were seated at a table comfortably opposite the investigator, and they were then presented with all nine materials samples one at a time, in a random order. Participants were instructed to assess five parameters "smooth-rough", "slippery-grippy", "coldwarm", "soft-hard" and "like-dislike" by moving the index finger of their preferred hand (right-handed and/or lefthanded) over all nine materials using reciprocating motion "forwards and backwards" scan mode, starting on the left side and ending at the right side. No time limit was enforced for each assessment and participants could stroke or press the polymer surface as many times as they wished (they were supervised to use the same pressure for each sample). Typically, within tens of seconds, judgments were made for each attribute. This procedure was repeated for all of the participants. The data presented in this part of the experiment were obtained from 40 people, three measurements for each sample, at different times and dates over a one-month period. The total experimental time per participants was about one hour. It is vital to note that respondents were only asked how each specific touch made them feel and not what the motivation of the toucher might be.

Figure 2 shows the responses scales developed and used to rate the five parameters, always in the order listed using visual analog type scales printed on the paper sheets (from 1 to 7). These attributes have been established as salient dimensions of tactile perception. All values were noted down by the investigator during the session of experiment.





# **3. Results and Discussions**

## 3.1 Questionnaire Test Performance

The nine polymer sample sets consist of visible interior materials used in, for example., passenger cars with regard to their aesthetic appearance and indeed feel. Such materials as polypropylene  $(C_3H_6)_n$ , polycarbonate (PC), and acrylonitrile butadiene styrene  $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z)$  are frequently used in passenger car interior components design. They can be self-colored by incorporation of pigmentation into the resin or painted or coated to achieve the appearance required. Their visible appearance is usually embossed with a grain

pattern "Yukon", "Stripple 005", "N111" and "N127" to effect improvements and hide surface deficiencies for instance minor sink marks and flow lines that occur as a result of the molding process and part design. Thermoplastic elastomeric (TPE) materials (or thermoplastic rubbers) are also used to cover control knobs and switches to improve their sensation and to meet head and knee impact regulations if the parts protrude. They are used to cover the storage area to prevent items sliding and rattling during driving.

Within the blind observers, there is only one tactile perception in this case which is the finger touch (tactile sensory input) and based on this assumption (60% contribution in tactile sensory input and 0.0% contribution in visual sensory input) only one contribution will participate in the decision, and 40% of the decision does not count as visual sensory input. Hence, the level of confidence is approximately 60%. However, there is a strong correlation between the pattern for both genders for blind observers to choose  $S1_{(Men)} = S1_{(Women)}$  as the softest materials (or preferred materials). On the other hand, there is no correlation found between blind observers and sight observers and surface roughness,  $R_a$ .

Figures 3 to 11 show the results of the averaged values for perception response of ("*smooth-rough*", "*slippery-grippy*", "*cold-warm*", "*soft-hard*" and "*like-dislike*") for all nine polymer samples.







Figure 4: average perception response for S2



Figure 5: average perception response for S3



Figure 6: average perception response for S4







Figure 8: average perception response for S6



Figure 9: average perception response for S7



Figure 10: average perception response for S8



Figure 11: average perception response for S9

#### **3.2. Friction Test Performance**

The coefficient of friction, CoF, and friction force,  $F_{f}$ , in unlubricated contacts were studied under the ambient condition using the universal surface tester (BASALT<sup>®</sup>, Precision Tester, TETRA). It consists of three basic units namely precision motion mechanisms, a bending element (force transducer double leaf spring, typically 1 cm length) and fiber-optic sensors to detect the normal and lateral deflections of the force transducer. There are various drives incorporated within the test-rig for positioning the nine samples and the 1 mm diameter steel ball (AISI 440C), providing reciprocating motion and for normal force adjustment. The positioning units serve to position the sample in the x-y axis, or the counterbody mounted on the bending element in the z-axis, respectively. These motions are achieved using stepper motors with resolution  $\pm 2.5 \ \mu m$ . The motion range from the initial position is 10 cm in x-yaxis and 5 cm in the z-axis. The reciprocating motion of the sample is realized by using linear bearing which is connected to the free of a piezoelectric element. The fixed end of this flexes back and forth in the x-axis and either push or pulls the linear bearing. In this way, a reciprocating motion in the range of ±0.5 mm is achieved. The sample was mounted using suitable adhesive on the top of a sample holder that is fixed to the linear bearing assembly. The tests were carried out under essentially wear-free conditions with normal loads 10, 20, 30, 40 and 50 mN, 125 µm/s sliding velocity, 0.21 Hz frequency, 300 µm stroke and the steel spring constant were  $k_{\rm N} = 608 \pm 26$  N/m and  $k_{\rm L} = 993 \pm 28$  N/m. All nine polymer samples were slid against the counterbody in the reciprocating mode for ten cycles during which time the friction force,  $F_f$ , was continuously recorded, as shown in Figure 12. After completion, the reciprocating "forwards and backwards" motion was stopped, the counterbody withdrew from the sample surface and moved to a new position located at 200 µm from the previous one. The test was then repeated with a higher load until the maximum load was reached. The

coefficient of friction,  $\mu$ , was recorded in all nine samples as shown in Figure 13. Only seven samples were below  $\mu =$  0.35, as shown in Figure 14, and the other two samples S2 and S3 illustrated the highest coefficient of friction ( $\mu \approx 1.1$ at low load and  $\mu \approx 0.2$  at high load). The friction force,  $F_{f}$ , was determined during the test as a function of the normal load on all nine polymer samples, as shown in Figure 15, with a strong linear relationship  $\mathbb{R}^2 > 0.9$ .



Figure 12: bending element and sample to be tested



Figure 13: coefficient of friction *vs.* the load results for all nine polymer samples



Figure 14: coefficient of friction *vs.* the load results for only seven polymer samples that  $\mu$  below 0.35



Figure 15: friction force *vs*. the load results for all nine polymer samples. The solid lines have been drawn to guide the eye

Figures 13, 14 and 15 show the coefficient of friction, CoF, and friction force,  $F_{f}$ , against the load for 1 mm diameter steel ball as a counterbody running against all nine samples in a reciprocating scan mode. These graphs indicate two critical trends. The first observation as regards the results plotted in the graphs is that the coefficient of friction decreases as the load increases from 10 mN to 50 mN. At low loads, these decreases are more significant than at higher loads when the coefficient of friction reaches a fairly stable level. The second observation is related to the friction force. The results indicate that the friction force correlates rather well with Amonton's law ( $F_f = \mu \times F_N$ ): the linear assumption still appears to dominate at 10 mN load, but the behavior of the coefficient of friction suggests that the assumption is just starting to break down. This phenomenon is generally attributed to surface chemistry effects and modification of softer surface though ploughing behaviours.

Interestingly, S9 represents the lower coefficient of friction,  $\mu \leq 0.05$  and friction force below ~2 mN with  $R^2 = 0.9861$ . For the micro-friction test, all nine sample can be rearranged from a low coefficient of friction to a high coefficient of friction as S9 < S8 < S5 < S4 < S7 < S6 < S1 < S3 < S2. This indicates that a larger contact area leads to greater friction when surface roughness takes effect in contact. In all, the friction depends on the real contact area and shear strength of interface. Meanwhile, the real contact area is related to deformation (or surface strength) and surface topography. Therefore, selection of surface topography and mechanical property could result in a significant tribological behaviour. These are very encouraging results, which are very consistent with sight observers results published earlier in [7], which indicated that S9 represented the smoothest surface and the preferred one. Moreover, S2 and S3 (glass fiber reinforced thermoplastic polyolefin compound for injection moulding) observed similar dry frictional behaviour. Also, surface roughness appears to be the dominant factor in touch perception, meaning that roughness is the primary sensation when people (whether sighted or blind) are exploring materials by touch. As a physically measurable quantity, roughness refers to height differences that occur in the profile of a surface.

Although perceptual roughness is much more complicated than this, as it depends on various other factors such as friction, stickiness, and pressure of touch, it may be that physical measurements of surface roughness,  $R_{\rm a}$ , still provide a good estimate of perceived roughness.

#### 3.3. SEM Test Performance

The surface topography of all polymer samples was analysed by Scanning Electronic Microscopy (SEM) of ten scan areas (scan size: 10  $\mu$ m  $\times$  10  $\mu$ m) measured at randomly located regions on the sample surface. To study the surface visualization and to improve the reflectivity for a higher fidelity in optical profiling, all samples were fully coated with gold using Bio-Red SEM Coating System, after all participants had examined the nine uncoated specimens. Figure 16 shows the polymer sample and fully gold coated 25 nm thickness (60 seconds). An approximation of the thickness of the deposited gold film measure may be derived from the following Equation (1):

$$d = mA \times kV \times t \times k \tag{1}$$

where; mA is the reading in milliamps on the meter, kV is the kilovolt setting, t is the time of the discharge in seconds, k is an experimentally derived constant which is approximately 0.017 for argon (0.004 for air) and d is the thickness in

nanometers, and the target to specimen distance is 50 mm. Thus, in this investigation, d is equal to 25 nm/minutes.

Figure 17 shows the SEM for all nine polymer samples that were used in this investigation. As can be seen, a porous foam structure with a number of bubbles crush defects is found in S3. In contrast, no bubbles but burnt and melted bumps are observed on the S1, S5 and S6. Besides, more debris of polymer blend is observed on S7 than on S4. The topography feature of all nine samples indicated that the highest surface roughness was S8. Also, S1 and S2 are similar in morphology and colour while, S9 appears to be the smoothest one.



Figure 16: (a) uncoated sample and (b) fully gold-coated sample (25 nm thickness)



S7: Softell TKS 209N (N127)



S8: Hostacom ERC 342N (N111) Figure 17: SEM observation of polymer coating

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**S9:** Hostacom ERC 342N (N127)

## 4. Correlations

Although the sense of touch is extremely advanced in detecting different tactile material properties, it is also essential to consider the role of vision upon the overall perception of material. It is well known, for example, that color has a definite influence on perceived warmth [6]. Furthermore, there is evidence that sight plays a significant role in judgements of softness and compliance [8]. Figure 18 shows the correlation between all participants (sighted and blind) and the average surface roughness,  $R_{a}$ , of all nine polymer samples. Sighted and blind conditions were used throughout the entire project (for the two phases) to study the effect of vision upon perception. In general, it was found that the physical properties studies are good predictors of perceived qualities. There is indeed a difference in performance as regards haptic perception of roughness between sighted and blind observers. On the other hand, no

differences were observed within the groups in terms of gender (women and men).

Accordingly, it can be said that the visual perception of texture gives significant observer information about the surface of an object or even the depth of a plane. This argument is supported by many authors, e.g., [9]-[11]. Moreover, other researchers in [5], [12] revealed that the surface properties of an object are often primarily perceived through a vision which then guides the tactile system to explore the surface. Indeed, this proposal is consistent with the results that are reported in this paper, and an earlier published study published [7].

Like touch, the vision system helps explore the external information in an active and dynamic way through a series of eye movements and fixation over the stimulus of interest.



Figure 18: Results of the averaged values of men, women and average roughness

# 5. Conclusions

From the work presented in this paper, the following conclusions can be extracted:

- *Blind Observers Results:* there is a strong correlation between the pattern for both genders. Both genders prefer S1 material as the smoothest one,  $Blind_{(Women)} = Blind_{(Men)} = S1$ .
- Sighted Observers Results published earlier in [7]: there is a strong correlation between the pattern for both genders for S5. Besides, S9 material was also preferred as the smoothest one for women's results,  $See_{(Women)} = See_{(Men)}$ ,  $S5_{(Women)}$  and  $S9_{(Women)} = S5_{(Men)}$ .
- Surface Roughness,  $R_{av}$ , Results: the smoothest material has been found to be S9<sub>(Ra)</sub>. There is a strong correlation between sighted<sub>(Women)</sub> and surface roughness<sub>(Ra)</sub>. On the other hand, there is no correlation between blind<sub>(Women, Men)</sub> and  $R_{a}$ .
- *Friction Properties Results:* S9 represented the smoothest material among all nine polymer samples.
- *SEM Results:* S9: Hostacom ERC 342N (*N127*) shows the smoothest topography among all nine sample surfaces.

The above conclusion can therefore be reached within the sight observers; there are two of tactile perception by finger touch that can help and stimulate to make the final decision "*tactile sensory input*" and "*visual sensory input*". So, 60% contributed in the tactile sensory input, and 40% contributed in the visual sensory input, with a 99.7% ( $\pm 3\sigma$ ) level of confidence. On the other hand, within the blind observers, there is only one tactile perception by finger touch that can help and stimulate to make the final decision "*tactile sensory input only*". So, 60% contributed in the tactile sensory input, and 0.0% contributed in the visual sensory input, with a 60% ( $\pm 1\sigma$ ) level of confidence.

The complexity of parameters makes psychophysical research in the field of haptically perceived gliding properties difficult. Therefore, only carefully planned studies, pursuing slow step-by-step approaches, will finally lead to applicable results. Research has only just begun, and product designers, as well as manufacturers, have an urgent need for practical results. Crossing the borders of professions to join forces will certainly accelerate processes in haptic research.

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