MULTIDIMENSIONAL PSYCHOPHYSICS: SURFACE FEEL OF PRINTING PAPER AS A FUNCTION OF PHYSICAL PROPERTIES

Martin Arvidsson[1], Birgitta Berglund[1], Lisa Skedung[2,3], Maiju Aikala[4], Katrin Danerlöv[3], John Kettle[4], Mark Rutland[2,3]

[1]Department of Psychology, Stockholm University and Institute of Environmental Medicine, Karolinska Institutet, SE-106 91 Stockholm, Sweden

[2] Department of Chemistry, Division of Surface and Corrosion Science, Royal Institute of Technology, Drottning Kristinas väg 51, SE-100 44 Stockholm, Sweden

[3] Institute for Surface Chemistry, P.O. Box 5607, SE-114 86 Stockholm, Sweden

[4] Oy Keskuslaboratorio - Centrallaboratorium Ab, PB 70, FI-02151 Espoo, Finland

Email: martin.arvidsson@psychology.su.se or birgitta.berglund@ki.se

Abstract

The aim of this experiment was to explore the perception of tactile surface-feel of 21 printing papers. A multidimensional scaling (MDS) experiment was conducted with 20 women. They scaled similarity among all possible pairs of the papers. Similarity measurements were mapped by INDSCAL and modeled with PREFMAP. Test-retest and concordance coefficients were high. It is not yet established what physical properties best determine tactile feel. It seems likely though that finger friction and surface roughness are strong contenders. Finger friction for the papers was measured as a ratio of friction force to normal force; while stroking a human finger on the surface. Average surface roughness was measured with a profilometer. Physical properties were rotated into the 3D INDSCAL solution. This solution identified and mapped the tactile surface feel of the papers in an interpretable way with regard to i.e. friction, surface roughness and weight.

There has not been as much research on haptic perception as there has been in the other senses. Moreover, current efforts often explore objects and/or applies probes. For example, Hollins, Bensmaïa, Karlof, and Young (2000) successfully conducted a dissimilarity experiment on different objects. They found two robust dimensions (rough/smooth and soft/hard) and a third less robust dimension (sticky/slippery). Five participants accomplished the perception by dragging a finger over the presented stimuli (haptic touch). The idea of active touch rather than passive touch is important because of the complex nature of touch, involving not only the feeling on skin but also in limbs and joints to create the perception. Also there are few experiments that are combining physical measurements of artificial surfaces with measurements of perceptions (e.g. Childs & Henson, 2006).

In this experiment, the goal is to explore dimensionality of haptic surface feel on a specific kind of materials, rather than for different objects or manufactured surfaces. Another goal is to determine how surface feel relates to physical qualities of the materials. It is not yet established what physical properties best determine the feel of surfaces. It seems likely though that finger friction and surface roughness are important physical qualities (Tiest & Kappers, 2006).

Table 1. The 21 printing papers and their characteristics.

Printing Paper	Code & Weight (g)	Coating	µ Loop 1-3	Ra
Light weight coated mechanical	LWC 45	Coated	0.298	2.00
Light weight coated mechanical	LWC 60	Coated	0.290	1.80
Machine finished coating	MFC 48	Coated	0.313	2.50
Machine finished coating	MFC 60	Coated	0.309	2.40
Woodfree uncoated	WFU 100	Uncoated	0.277	3.80
Woodfree uncoated	WFU 60	Uncoated	0.284	3.90
Newspaper	News 45	Uncoated	0.276	4.00
Supercalandered, virgin fibres	SC-A 48	Uncoated	0.300	2.00
Supercalandered, recycled fibers	SC-B 60	Uncoated	0.364	2.20
Supercalandered, recycled fibers	SC-B 45	Uncoated	0.359	2.10
Supercalandered, virgin fibres	SC-A 60	Uncoated	0.296	1.90
Woodfree coated	WFC-Gloss 100	Coated, hf	0.476	1.20
Woodfree coated	WFC-Gloss 115	Coated, hf	0.431	1.20
Woodfree coated	WFC-Gloss 130	Coated, hf	0.385	1.20
Woodfree coated	WFC-Gloss 70	Coated, hf	0.453	1.30
Woodfree coated	WFC-Matt 100	Coated, lf	0.423	1.70
Woodfree coated	WFC-Matt 70	Coated, lf	0.411	1.70
Woodfree coated	WFC-Silk 115	Coated, mf	0.381	1.50
Woodfree coated	WFC-Silk 130	Coated, mf	0.378	1.60
Medium weight coated	MWC 100	Coated	0.364	1.30
Medium weight coated	MWC 60	Coated	0.353	1.50

Footnote. hf = high finish, mf = medium finish, and lf= low finish.

The Experiment

Participants

Participants in the experiment were 20 women between 20 and 37 years old. Monetary compensation was given for their participation.

Stimulus Materials

Twenty-one different kinds of printing papers were received from KCL, Finland. Specifics about the stimulus papers are found in Table 1. The papers were stored in clearly labelled boxes sorted in numerical order from 1 to 21. The day before each new participant was tested, each of the paper sheets were individually marked in the lower right corner before being moved to their corresponding shelf in the test room. All the shelves were covered to prevent the participants from seeing the materials before they were blindfolded. There was a unique random order of the pairs for each participant.

Design and Procedure

Each paper was paired up against every possible combination of the other papers including itself (i.e. 1-1, 1-2...1-21; 2-2, 2-3…2-21; etc…21-21) in a 21 x 21 matrix where one half of the matrix was tested. For test-retest reliability, every pair including paper 1 or paper 21 were included twice as well as all the pairs along the one diagonal adjacent to the main diagonal in the matrix (i.e. 1-2, 2-3, 3-4, etc...20-21). In total there were 293 pairs of papers. Each individual sheet of paper was only used for one comparison.

The participants were instructed to judge similarity between pairs of papers on a scale ranging from 100% similar to 0% similar (e.g. if two papers were perceived as identical the participant would say 100). They were told to use their preferred hand and that they had to use the same hand for the whole duration of the experiment. They were instructed to freely explore the surface with their hand, including all their fingers, but they were not allowed to pick the paper up. They were allowed to feel back and forth between the papers in the pair until they felt confident to make their similarity judgement. After receiving the instructions, the participants were blindfolded (TEMPUR Sleep Mask) and the experiment began. The experiment was divided into sessions with breaks in-between. The sessions were 25 min long and were followed by a 20 min break. There was some variation in the length of the experiment due to the individual pace of the participants. However, the participants were normally finished in 5 test sessions, some 6. A hygrometer was used to measure temperature and humidity in the testing room. Analyses were conducted with INDSCAL and PREFMAP.

Physical Measurement

Physical measurements of two qualities were conducted: finger friction and surface roughness.

Finger friction: A macroscopic friction device was used to measure friction between a *human finger* and the different printing papers in order to get a physical measurement of friction. The device consists of a piezoelectric force sensor (Kistler 9251A) and measures the friction force (F_F) and the normal force (F_N), while stroking an experimental finger over the surface. The friction coefficient (µ) is calculated as the ratio of the friction force to the normal force according to the Coulomb friction law ($F_F = \mu \times F_N$). The force transducer is mounted between two parallel steel plates and the paper samples ($4\times5\ cm^2$) were mounted on the top plate with double sided adhesive tape, see Figure 1. The force sensor was calibrated in order the get the output signal (the two forces) in Newton instead of voltage. The measurements were performed at a temperature within the range 22-24°C and a relative humidity within the range 17-24 %. The mean friction coefficient of the first three striking cycles were used as the physical (finger) friction measure: Friction was measured between a human index finger and the different papers with a piezoelectric device, and the friction coefficient were calculated as the ratio of the friction force to the normal force

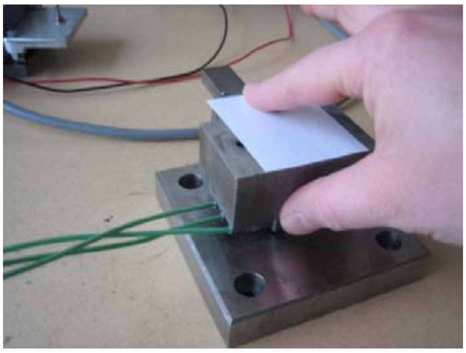

Figure 1. The finger friction apparatus used to measure friction coefficients between a finger and printing papers.

Surface roughness: The average surface roughness (R_a) was measured with a profilometer. To characterize surface roughness, a NanoFocus µScan laser profilometer was used to measure R_a (average surface roughness), which is the arithmetic average deviation of all points *x* from the center line of the test surface:

$$R_a = \frac{1}{L}\int_0^L |z(x)|dx, \qquad (1)$$

where *L* is the length of the profile line and *z* is the surface height over the center line. Mathematically the center line is defined in such a way that the sum of the *z* values is zero.

Results

Finger Friction and Surface Roughness

There is a trend that rougher (R_a) papers have lower friction than the less rough (R_a) papers, shown in Table 1. One possible explanation is that there are more contact points between a finger and a less rough paper than a more rough paper, therefore resulting in higher friction. The WFC papers have the highest friction and News and WFU have the lowest friction. The coated papers, made with mechanical pulp, and the supercalandered papers are placed intermediate. The finger friction and roughness measurements are more extensively described elsewhere (Skedung, et al., 2008).

Multidimensional Scaling of Surface Feel

The concordance between participants was good. A split half comparison of the first 10 participants' 210 unique scale values against the last 10 participants showed a correlation of 0.92. The test-retest data was very good, the average first scale value and the average second scale value of the 56 repeated pairs for all participants correlated with 0.88. The similarity data was analysed with INDSCAL and the inter distances between the 21 different stimuli were best represented in a 3D space (shown in Figure 2).

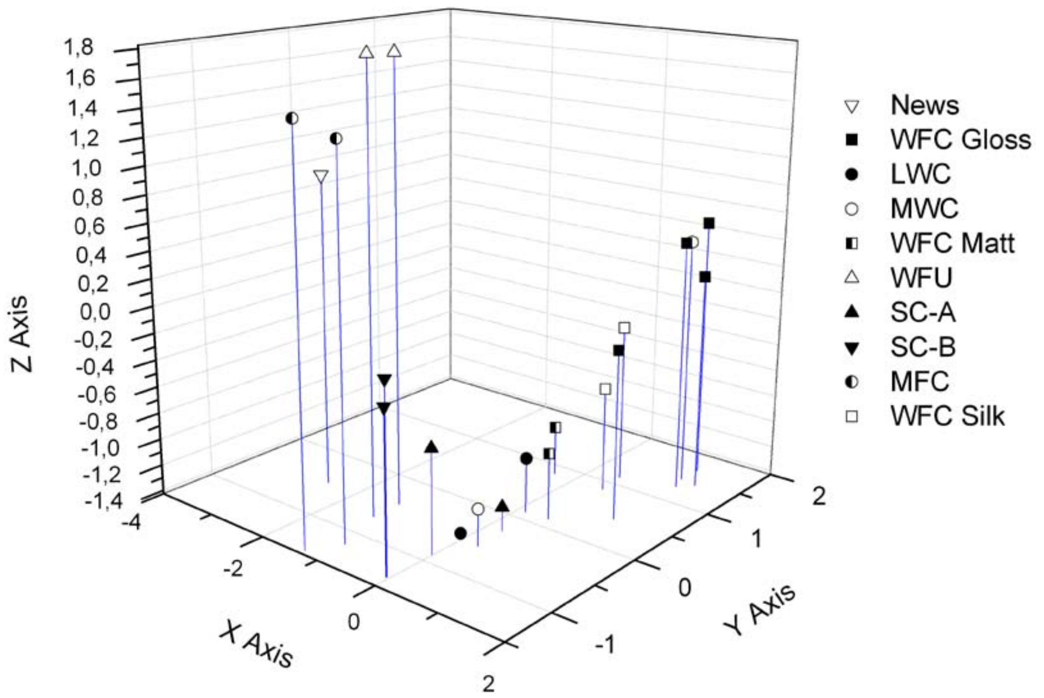

Figure 2. The 3D INDSCAL representation of perceived dissimilarities of 21 printing papers.

Participants were very good at scaling the similarities of the 21 papers both test-retest and concordance data suggest that haptic tactile perception is sensitive in discriminating between different kinds of printing paper. Another valuable finding is that the participants clearly perceived the difference between coated and uncoated papers and that the supercalandered paper with new fibres was perceived similar to the coated papers whereas the supercalandered paper with recycled fibres was perceived as more similar to the uncoated papers.

There was a distinct perceptual difference between the rough (uncoated) and less rough (coated) papers. The grammage of the papers seemed to relate more closely to the vector of the coated papers, which could mean that heat conductivity (which is likely to vary with the density of the papers) might be an important physical contributor in surface feel. We intend to measure and include this at a later stage.

Finger friction, surface roughness and grammage was fitted into the 3D INDSCAL solution. Dimension 1 against 2 and Dimension 1 against 3 are plotted in Figure 3.

Conclusion

In conclusion, the participants performed well on the task of scaling similarity of the materials of the same class and did so in good concordance as well as in test-retest (r=.92 and r=.88 respectively). The physical measures could be fitted into a 3D INDSCAL solution. The 2 dimensions found by Hollins, Bensmaïa, Karlof, and Young (2000), rough/smooth and hard/soft, are partially supported in this experiment. The rough/smooth dimension gets supported by the fit of finger friction and surface roughness. The hard/soft dimension is a bit hard to relate to different printing-papers but the grammage separation of the papers suggests there is something to the body of the papers that is of importance for the second dimension (y-axes). A follow-up experiment is planned to match verbal descriptors to the feel of papers to better understand the dimensionality.

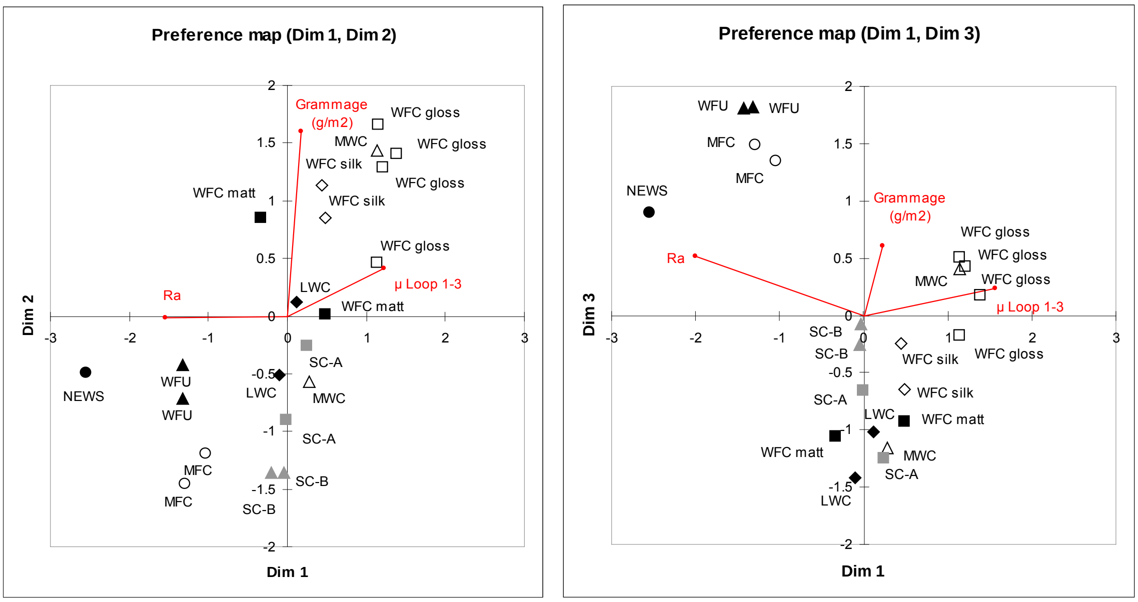

Figure 3. Finger friction, surface roughness and grammage fitted into the 3D INDSCAL solution of perceived dissimilarity (Fig. 2).

Acknowledgement

The research was made possible by funding from the Institute of Excellence CODIRECT, founded by Swedish VINNOVA and hosted by the Institute of Surface Chemistry, Stockholm, Sweden. Special thanks go to KCL, Finland for providing stimulus materials and physical measurements.

References

Childs, T.H.C., & Henson, B. (2006). Human tactile perception of screen-printed surfaces: self-report and contact mechanics experiments. *Special Issue Paper*, 221, 427-441.

Hollins, M., Bensmaïa, S., Karlof, K., & Young, F. (2000). Individual differences in perceptual space for tactile textures: evidence from multidimensional scaling. *Perception & Psychophysics*, 62, 1534-1544.

Skedung, L., Rutland, M.W., Danerlöv, K., Aikala, M., Olofsson, U., Kettle, J., & Niemi, K. Finger-Friction of coated and uncoated printing papers of different paper grades. *In Proceedings of the International Conference in Tribology*. Singapore, December, 2008.

Tiest, W.M.B., & Kappers. A.M.L., (2006). Analysis of haptic perception of materials by multidimensional scaling and physical measurements of roughness and compressibility. *Acta Psychologica*, 121(1): p. 1-20.