Article:

Mylon, P.T., Buckley-Johnstone, L., Lewis, R. et al. (2015) Factors influencing the perception of roughness in manual exploration: Do medical gloves reduce cutaneous sensibility? Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 229 (3). 273 - 284. ISSN: 1350-6501

https://doi.org/10.1177/1350650113517111

Factors influencing the perception of roughness in manual exploration: do medical gloves reduce cutaneous sensibility?

Peter T Mylon[1], Luke Buckley-Johnstone[1], Roger Lewis[1], Matt J Carré[1] and Nicolas Martin[2]

[1]Department of Mechanical Engineering, The University of Sheffield, UK

[2]School of Clinical Dentistry, University of Sheffield, UK

Corresponding Author

Peter Mylon, Eurolens Research, The University of Manchester, Carys Bannister Building,
Room 1.017, Dover Street, Manchester, UK, M13 9PL.

Email: peter.mylon@manchester.ac.uk Tel: (0161) 275 5574

Abstract

A new roughness perception test was designed to evaluate cutaneous sensibility. Blindfolded subjects explored a sample of sandpaper using one of two methods: stroking the sample (dynamic method), or applying pressure (static method). A range of samples of various grades were presented in a random order, and subjects scored each one in terms of perceived roughness. Each subject performed the test in three conditions – wearing latex and nitrile examination gloves and bare-handed. Mean normalised scores for each combination of sandpaper grade and hand condition were calculated. The COF between each sample and glove (or bare finger) was measured, and the topography of each sample was analysed using a profilometer. It was found that the COF did not vary significantly across the samples, and so could not be related to perceived roughness. However, there were strong correlations between perceived roughness and surface topography (roughness average, particle diameter, particle spacing), particularly in the dynamic method. In the static method, most subjects did not perceive roughness differences below 800 μm particle spacing. In both methods, there was a significant reduction in perceived roughness when gloves were donned, but no significant difference between the two glove types could be found. It was concluded that the dynamic method was a useful test for evaluating cutaneous sensibility. Further investigation of the relationship between friction and perceived roughness was recommended, using a wider range of sample materials.

Keywords

Roughness, perception, friction, gloves, tactility

1. Introduction

Tactile exploration is an essential tool in medical practice. It allows clinicians to identify abnormalities and areas of interest in tissue, and is a vital part of both diagnosis and treatment. Tactile feedback is also a crucial component of grasping and manipulation, enabling clinicians to apply the appropriate forces to tissues and to grasp instruments with sufficient, but not excessive, force.

Natural stimuli on the body are processed by sensory receptors located in skin, muscles and joints. The glabrous (non-hairy) skin of the hand contains various tactile units, consisting of afferent fibres and endings, that measure force (mechanoreceptors), temperature (thermoreceptors) and pain (nociceptors). Of the estimated 17,000 mechanoreceptors, about half of these are fast adapting (FA), i.e. they respond with a burst of impulses only at the onset and removal of the stimulus. The other half are slow-adapting (SA) – they respond with a sustained discharge.

These can be split into two further categories (I and II). FA I and SA I have small and well-defined receptive fields and are very sensitive to edge contours denting the skin, as opposed to the whole field being depressed, so are useful in spatial discrimination. FA II and SA II (30% of afferents in glabrous skin of hand) have a single zone of maximal sensitivity and wider surrounding area with gentle fall-off. They are located deep in the dermis and subcutaneous tissues, and are sensitive to vibration and lateral skin stretch respectively.[1-3]

Cutaneous sensibility (the ability to detect external stimuli on the skin) varies depending on a number of factors, such as spatial acuity (the distance between tactile units) and friction. It can also be impeded by the introduction of a barrier between the skin and the object being explored. Hence, the introduction of medical gloves for reasons of infection control may have an unintended impact on the ability of clinicians to perform their duties effectively and safely.

Various methods have been proposed to describe how we use our fingers to explore our environment. However, because each type of tactile unit responds to different types of stimuli, no one test can fully describe tactile function. A further distinction exists between active and passive sensing, where active sensing (movement of the fingertips over a static object) uses both muscular and cutaneous cues, whereas passive sensing (the movement of an object over a passive fingertip) excites only the cutaneous sensors.

Perhaps the most common test of cutaneous sensibility is the Semmes-Weinstein Monofilaments test, in which a force is applied to a static fingertip by a monofilament in order to determine the threshold force that elicits a response. Various studies[4-7] showed that medical gloves increase the threshold force (i.e., reduce cutaneous sensibility). However, this method does not simulate the tactile exploration that is involved in many medical tasks.

A more realistic measure of tactile performance may be found in roughness discrimination. The “Roughness Discrimination Test”[8] consists of 69 cards on each of which four squares of sandpaper are mounted. Three of the squares are of one grade, and the fourth is of another. Subjects are required to run their finger across each square and identify the “odd one out”. Two studies[9, 10] compared the roughness discrimination of different gloves, and Wilson, Gound, Tishk, and Feil[11] compared gloved and ungloved performance when using a dental explorer to stroke the surface. None of them found significant differences, although two of them found a perceived difference in ability. Another roughness discrimination task[12] also found no reduction in tactility from gloves and no difference between gloves. The presence of perceived differences suggests that the either tests are not adequately assessing tactile ability or that gloves affect the confidence of the wearer but not their actual ability to discriminate.

An alternative method was proposed in which, instead of asking the subjects to correctly identify a difference in roughness, the aim was to quantify the perceived differences in roughness between sandpaper samples with a range of grit sizes. The procedure was adapted from Skedung et al.[13], in which the test was carried out on paper samples, and is based on the magnitude estimation method, a form of psychophysical ratio scaling, described in Stevens[14]. It was hoped that allowing subjects to score the roughness on a scale of their choosing would bring out any tactile performance differences that were too subtle for the Roughness Discrimination Test.

In the study by Skedung et al.[13], the subject was required to stroke the sample with the index finger in order to determine its roughness. In this study, it was decided that, in addition to this dynamic exploration method, a separate experiment would be performed in which subjects were only permitted to use static pressure (i.e., no sliding) to determine the roughness of the surface.

The aims of the study presented here were to:

- determine the suitability of roughness perception testing for evaluating cutaneous sensibility;
- investigate the effect of medical gloves on cutaneous sensibility;
- explore the relationships between glove properties, such as friction, topography, elasticity and thickness, and perceived roughness;
- investigate the importance of motion in tactile sensing.

2. Methods

2.1 Ethical approval

Approval for the research was obtained from the University of Sheffield Research Ethics Committee.

2.2 Participants

The testing was carried out in two parts, since it formed part of two separate studies. Nine subjects, all of whom were undergraduate students at The University of Sheffield (Sheffield, UK), participated in the first part. In the second study, conducted at BM Polyco Ltd. using the same apparatus and procedure, 21 people volunteered to participate, all of whom were BM Polyco Ltd. employees. None had any known sensorimotor deficiencies or other major health problems. Of the 30 subjects, 16 performed the test using the standard dynamic procedure, and 14 used static pressure only.

2.3 Gloves

Two types of PolycoHEALTHCARE examination glove were used in the study – 'Finex PF' (latex) and 'Finite P Indigo AF' (nitrile). Since differences in thickness and elasticity between the gloves were apparent, which could have a significant effect on tactile sensation, both properties were evaluated. In order to measure the thickness, three gloves of each type were randomly selected. Three samples were cut from the smooth palmar/dorsal surface of each glove (so as to be flat and of sufficient size) using a 3mm wide BN EN 455:2000 dumbbell cutting die. The thickness at the centre of each sample was measured using a digital micrometer (Sylvac). The mean thickness was found to be 123 µm for the latex glove and 74 µm for the nitrile.

The test specimens were then placed in a tensometer (Instron Ltd.) and stretched at a rate of 500mm/min until failure occurred. Video equipment was used to track markers fixed to either end of the thin section of the dumbbell and thus calculate strain. The results were recorded in a stress-strain graph by the software (Bluehill®, Instron Ltd.).The mean tensile stress values for each of the gloves at the recorded intervals of strain are shown in Figure 1. The mean tensile stress at 200% elongation is shown in Table 1.

The subjects were allowed to choose the size of glove that fitted them best for each type, with some help from the researcher. Most participants in the second study had some experience of using examination gloves through previous testing carried out at the company.

2.4 Sandpaper grades

Seven grades of sandpaper were used, with either aluminium oxide or silicon carbide grains on latex backing paper. The Federation of European Producers of Abrasives (FEPA) grit designations and average particle diameters are listed in Table 2.

The grades were chosen based on preliminary testing, and give a marginally smaller range than the 24-600 (16-715µm diameter) CAMI grades used in Nolan and Morris's Roughness Discrimination Test[8].

2.5 Experimental design

A repeated-measures design was used for the experiment, i.e. each subject completes the test at each level of the independent variable, or 'within-subjects factor'. The within-subjects factor was hand condition, which consisted of three levels: 'No Gloves', 'Best-Fit Latex' and 'Best-Fit Nitrile'. Each subject therefore performed the test (either static or dynamic) in all three hand conditions (in a random order), and subjects were instructed to maintain the same scale across all hand conditions to allow a fair comparison.

2.6 Procedure

Before the test, subjects were given verbal instructions in how to perform the test and in the method of magnitude estimation. The subjects sat at a table and were blindfolded. A cardboard guide was placed in front of them to allow them to locate the sandpaper (Figure 2). A randomly-selected sandpaper sample was placed in the guide, and the subject was instructed to feel the sample. In the dynamic test, this involved lightly placing their dominant index finger at the far end of the sample and drawing it slowly back towards themselves until they reached the end of the sample. In the static test, it involved pressing the fingertip onto the sample without moving it horizontally, and lifting it off again.

For each sample, the subject was required to assign a numerical score that corresponded to the perceived magnitude of roughness. They were allowed to set their own scale from the first sample that was presented, with any positive, non-zero value being allowed. Subsequent samples were scored relative to previous ones, so that if a sample was twice as rough as the previous one, the score would be twice as high. The samples were presented in a random order, with each sample being presented multiple times. In the first study, each sample was presented seven times (following the method of Skedung et al.[13]), but was reduced to three in the second study in order to decrease the test duration. It was felt that the consistency in individual scores for each sample meant that presenting each sample seven times introduced unnecessary redundancy in the results.

3. Roughness and friction

3.1 Roughness measurement

The FEPA grit designation is based on particle size. However, there are other factors that may influence the perception of 'roughness', such as the particle spacing and shape. Another way of quantifying the roughness of a surface is the roughness average (R_a), which expresses the arithmetic average of absolute values of height along a two-dimensional profile. A profilometer (Surftest SJ-400, Mitutoyo) was used to measure the R_a value of the sandpaper. Five samples were taken from each grade. A 12.5 mm profile was measured on each sample and split into five equal evaluation lengths. The roughness average was calculated for each evaluation length and the mean of the 25 measurements taken as the R_a value for each grade. Examples of the measured 2D profiles are shown in Figure 3.

The measured profiles were also processed using a MATLAB script that identified the major peaks (based on the function peakfinder.m; Copyright © 2009, Nathanael C. Yoder, all rights reserved). The average distance between the peaks (assumed to be the average particle spacing) was recorded for each grade. The results are shown in Table 3.

3.2 Friction measurement

Each of the seven sandpaper grades was attached with clamps to the University of Sheffield finger friction rig[16], as shown in Figure 4. The dynamic roughness procedure was performed in the ungloved condition and when wearing the latex and nitrile examination gloves, using a single subject (no roughness magnitude estimation was required). By lightly pushing down on the sandpaper sample, the subject applied a normal force of 1.5-2 N, which was kept relatively constant throughout the test by monitoring the instantaneous force measurement from the normal force load cell on a visual display. The finger was drawn along the sample towards the subject at an approximate sliding speed of 100-150 mm/s, for a distance of 50 mm. Friction force during the loading cycle was measured by a second load cell. The coefficient of friction (COF) is the ratio of the friction force to the normal force. Figure 5 shows an example of the data from the load cells and the calculated COF. For each sample, the average COF was calculated over the entire period of contact.

Both the gloves and sandpaper samples were regularly changed due to occasional transfer of particles from the gloves to the sandpaper. Combinations of hand condition and sandpaper grade were tested in a randomised order to ensure no false patterns emerged. Friction measurements were repeated 5 times for each combination. The resulting COF measurements are shown in Table 3.

4. Data analysis

Because each candidate used their own scale to quantify the roughness, and the ratings were based on relative magnitude, the arithmetic mean was not an appropriate measure, as it skews the results towards subjects who gave larger values and greater magnitude differences. Stevens[14] described a method adapted by Skedung et al.[13], that normalises and combines the results for all subjects as follows:

- Calculate the multiplier for each subject by dividing the grand mean of all magnitude estimations by the mean of the individual subject's magnitude estimations;
- Multiply each subject's magnitude estimations by their individual multiplier;
- Calculate the geometric mean for each sandpaper grade in each hand condition, where the geometric mean of n estimations is given by

$$Geometric\ mean = \sqrt[n]{x_1.x_2.x_3 \dots x_n}$$

Although subjects were instructed to give a non-zero score for the perceived roughness, some subjects were unable to detect any roughness in some samples, particularly in the static tests in the gloved conditions, and so gave a score of zero. (Of 294 subject-glove-sample combinations in the static test, 49 produced mean scores of zero.) Since any datasets containing zeros will have a geometric mean of zero, the median was used instead in such cases, as recommended by Ehrenstein and Ehrenstein[18].

Two basic forms of statistical analysis were used in this study – correlation and paired difference testing. To determine the strength and significance of any apparent linear dependence between two variables, such as friction and surface roughness, the Pearson correlation coefficient and the significance of the correlation were calculated. The closer the coefficient is to 1, the stronger the linear dependence of the two variables.

For the friction and perceived roughness tests, a repeated-measures design was used (i.e., each sandpaper grade was tested in each hand condition). Since there were only three levels of hand condition, paired difference testing was used to compare the performance of the three hand conditions (latex, nitrile and bare-handed) in pairs (i.e., three tests). For each sandpaper grade, the difference in the value of the dependent variable (COF, perceived roughness) between two hand conditions was calculated and the mean difference across the samples was compared with the error to find the significance of any difference in the means for the two hand conditions. The significance level used was 5% ($\alpha = 0.05$).

The standard paired difference test, the paired t-test, requires an assumption of normality. The extent to which each dataset followed a normal distribution was tested using the Shapiro-Wilk test. Where the results were found to differ significantly from normality, the Wilcoxon Signed Ranks Test was used. This is a non-parametric test that compares mean ranks rather than mean scores. It does not require an assumption of normality, but may reduce the apparent significance of any differences.

5. Results

The results of the measurements are shown in Table 3. The coefficients of friction for each of the seven sandpaper grades with each hand condition are plotted against measured roughness average in Figure 6.

The friction results for all three hand conditions were normal ($p \geq 0.297$). Dynamic COF for all three hand conditions was fairly constant across the range of sandpapers and does not correlate significantly with any of the three geometric measures (Pearson Correlations ≤ 0.585, $p \geq 0.168$). However, the nitrile gloves showed a significantly lower COF across the range than latex or bare hands. The results of the t-tests are shown in Table 4.

The relationship between the three geometric measures (R_a, particle diameter and average particle spacing) can be seen in Figure 7. There are strong and significant correlations between the three measures, as shown in Table 5.

The particle spacing for the P180-grade sample is larger than expected, but the roughness average fits the trend. Inspection of the profiles (see Figure 3) shows that there is a large variation in particle size in the P180 grade. In particular, there appear to be a number of particles that are much larger than the stated average diameter so that, although the particle spacing is large, the roughness average is closer to the expected value. The effect of each of the three measures on perceived roughness in the dynamic and static tests is explored below.

5.1 *Dynamic roughness perception*

There is a strong correlation between R_a and perceived roughness for all hand conditions, as can be seen in Table 5. Pearson correlations for roughness perception samples.
Table 6. Geometric mean perceived roughness is plotted against roughness average in Figure 8. It can be seen that the perceived roughness is highest in the ungloved condition for almost all values of roughness average. The perceived roughness is higher with latex gloves than nitrile at the rougher end of the scale. At the smoother end, the results merge together, as the roughness becomes too low to detect differences, even with bare hands.

The P180 grade (16.7 µm R_a) shows a higher than expected perceived roughness. This sample has a larger particle size, but the particles are spaced further apart. It is clear, therefore, that Ra alone cannot account for how roughness is perceived, and that particle size and spacing also play a part.

No significant deviation from normality was found in the dynamic roughness results ($p \geq 0.095$). Repeated-measures ANOVA using the geometric means from each of the seven grades showed significance for glove type ($p=0.007$). The results of paired t-tests are shown in Table 7.

Across the range of samples, perceived roughness was significantly higher in the ungloved condition, but the mean difference between the gloved conditions was not significant. When the paired differences in adjusted score between hand conditions were analysed for each candidate and grade ($n = 16 \times 7 = 112$) using the Wilcoxon Signed Ranks Test, the significance of differences between ungloved and gloved scores increased ($p=0.000$), but the difference between the latex and nitrile gloves was still not significant ($p = 0.758$).

The results did not show a significant linear relationship between the dynamic COF and the perceived roughness. The Pearson correlation was found to be 0.160 ($p = 0.489$).

5.2 *Static roughness perception*

The correlations between the three measures of geometry and the geometric mean perceived roughness for each sandpaper grade in the static test are shown in Table 8. The strongest correlations are found between particle diameter and perceived roughness. The relationship is shown in Figure 9.

It can be seen that for the largest particle size, the ungloved condition produced the highest perceived roughness value, while the latex again produced a higher perceived roughness value than nitrile. For particle sizes less than 150 μm, however, there was little difference in perceived roughness for the three hand conditions.

The distribution of the results deviated significantly from normality ($p \leq 0.005$), so the Friedman test was used to measure significance. It showed that hand condition did not have a significant effect on perceived roughness ($p = 0.066$). Since the p value was only just above the significance level, paired difference tests between the hand conditions were carried out. The results are shown in Table 9.

When the paired differences in adjusted score between hand conditions were analysed for each candidate and grade ($n = 14 \times 7 = 98$) using the Wilcoxon Signed Ranks Test, the significance of the differences between the ungloved condition and the gloved conditions increased ($p = 0.000$), but the difference between the gloved conditions was still not significant ($p=0.608$).

The results did not show a significant linear relationship between the dynamic COF and the perceived roughness. The Pearson correlation was found to be 0.110 ($p = 0.635$).

6. Discussion

Both the dynamic and the static tests produced significant differences in perceived roughness between the ungloved condition and the two gloved conditions. The reduction in perceived roughness with gloves can be attributed to a loss of cutaneous sensibility, and thus the tests can be said to be a useful indicator of loss of hand function, which has a number of uses in medical assessment, as well as in glove design. The dynamic tests showed more significant differences between hand conditions and more normal distributions than the static tests, but neither test was able to find any significant difference between latex and nitrile examination gloves in their effect on roughness perception.

Although the coefficient of friction was significantly lower with nitrile gloves than latex, this did not result in lower perceived roughness values in the dynamic test. It might be expected that the higher shear forces experienced with the latex gloves would affect perceived roughness. However, Taylor and Lederman[19] showed, through both a theoretical model and experiments with grooved tiles, that friction is not a significant factor in perceived roughness.

Since all of the samples produced similar coefficients of friction for a given hand condition, it was difficult to isolate any effects of friction on perceived roughness from those of thickness and elasticity. With the latex gloves being almost 70% thicker than the nitrile ones, a loss of cutaneous sensitivity might be expected, with the vibrations being damped and a weaker signal reaching the deep vibration-fired mechanoreceptors. However, the much higher elasticity of the latex gloves may mean that the actual thickness of the barrier under shear loading was comparable to that of the nitrile gloves. In order to isolate the effect of each of these properties on perceived roughness, the experiments would need to be repeated with customised gloves in which only one property was varied at a time.

No correlations were found between COF and surface topography (particle size and spacing, roughness average). This is in contrast to the findings of Skedung et al.[13], who measured friction between a fingertip and a range of papers and found an inverse relationship between the COF and the roughness average. They postulated that the relationship was due to a change in real contact area – rougher surfaces form less adhesive bonds and so create lower shear forces during sliding. However, the samples used in their study were much smoother (1-4µm R_a) than those in this study (4-63µm R_a).

Tomlinson et al.[17] tested an even wider range of roughness with a bare finger on three different metals, using the apparatus shown in Figure 4 (<1 – 100µm R_a). They found that at the lowest and the highest roughness the COF was independent of R_a, but that in-between (approximately 5-40 µm R_a), the COF increased with roughness. The results were not readily explained, although adhesive friction was thought to be an important factor.

One possible explanation for the lack of correlation between surface roughness and friction in this study may be that different mechanisms are at play that dominate in different regions of roughness. Derler and Gerhardt[20] collated data from a number of skin friction studies, and hypothesised that there are two friction regimes for dry skin in contact with surfaces of increasing roughness. For smooth surfaces, adhesive friction dominates, and the COF is dependent on the real contact area. As the roughness increases, the real contact area reduces, and so does the COF. However, for rough surfaces, deformation mechanisms such as ploughing (the tangential deformation of finger/glove by the sandpaper particles) and interlocking (the force required for ridges in the finger or glove to climb over the sandpaper particles) are more dominant. In this regimes COF increases with roughness, up to a plateau. The change in contribution of each of these mechanisms may lead to little overall change in shear force over the range of roughness tested. Further testing and analysis would be required to confirm this hypothesis, but it is clear from previous studies in this area that the relationship between roughness and friction, particularly where skin and other polymers are concerned, is far from simple.

Widening the range of grain materials (only silicon carbide and aluminium oxide were used) might produce a greater range of coefficients of friction and allow the relationship between friction and perceived roughness to be better understood. The friction results should also be corroborated with a larger subject sample size.

The biggest difference between the dynamic and static methods appears to be the ability of subjects to discriminate between the smoother grades of sandpaper. While the dynamic test showed a fairly linear relationship between perceived and measured roughness, in the static test there was little difference between the average perceived roughness values for the five smoothest grades, all of which were very low in comparison to the values recorded for the rougher grades (less than 20% of the 'No Gloves' average for the roughest grade) and showed no increasing trend with particle size. Kwok et al.[19] found a similar result in roughness discrimination tests with sandpaper – although discrimination was poorer in static tests than dynamic for both coarse and fine samples, the effect was more pronounced with the fine grades.

Hollins and Bensmaïa[21] examined the coding of roughness by analysing the results of a number of studies that used different methods to measure tactile perception. These included static and dynamic tests using sandpaper samples of varying grades, similar to the method set out in this paper, as well as etched silicon surfaces, raised dots and grooved gratings in which the spacing was varied. Their conclusions provide a possible explanation for the difference in results between the two tests. They asserted that there were two physiological mechanisms or "codes" by which we perceive roughness. "Textures with spatial periods exceeding about 200 μm are encoded spatially," by SA I afferents while "perception of the roughness of finer surfaces is mediated by detection... of cutaneous vibrations generated when textures move across the skin”. So smoother surfaces cannot be distinguished by deformation-fired mechanoreceptors; they require movement to generate vibratory signals. It should be noted that in the sandpaper-based experiments it is not possible to isolate the effects of particle size and spacing, since they cannot be independently varied, but the grooved gratings do allow independent variation of spacing, and the results certainly support the theory that the “spatial period” of the texture affects the mode of roughness perception.

In this study, the particle spacing, or spatial period, at which the perceived roughness started to increase in the static test was 800 µm in all hand conditions (see Figure 10), which is larger than Hollins and Bensmaïa’s value (which appears to be an approximation based on a number of different studies) but more importantly, the two-phase nature of the graph supports the theory that there is a threshold spacing below which vibratory signals are essential to roughness perception.

Gloves had a significant effect on both test results, so it is difficult to analyse which of the codes is most inhibited by wearing gloves. In terms of the usefulness of the tests in glove comparisons, neither a static nor a dynamic approach produced significant differences between the gloves. The dynamic test has the advantage of not producing zero-value responses, assuming that the method of magnitude estimation has been correctly explained and fully understood. Since the largest differences occurred with rougher surfaces, increasing the particle spacing and diameter across the range might yield better results.

7. Conclusions

The roughness perception test was found to be a useful indicator of cutaneous sensibility. The average perceived roughness of a range of sandpaper grades was significantly reduced when wearing examination gloves as compared to the ungloved condition. There were strong correlations between surface topography measures (particle size and spacing and roughness average) and perceived roughness.

Of the two test methods investigated, the dynamic method (where the finger was drawn across the sample) produced larger differences between hand conditions across the range of samples than the static test (where the finger was pressed onto the sample). However, neither method found significant differences between latex and nitrile gloves. Below 800μm particle spacing, most subjects were unable to detect differences between samples in the static test, even in the ungloved condition. This was thought to be because the deformation-fired mechanoreceptors are not activated by finer textures, which must be distinguished by vibratory signals caused by relative movement of the surfaces.

Roughness perception in the dynamic test was most closely correlated with roughness average, while in the static test it was most closely correlated with particle size. This reflects the different types of mechanoreceptor that were dominant in each method, with static sensing being primarily by deformation, while dynamic sensing uses vibratory signals.

The COF between the finger and the sandpaper was not found to correlate with either the perceived roughness or the surface topography. The friction values were very similar across the range of grades. In order to further investigate the effect of friction on perceived roughness, a wider range of materials should be used.

Funding

This work was supported by the Engineering and Physical Sciences Research Council [Doctoral Training Grant] and BM Polyco Ltd.

References

1. Johansson RS and Vallbo AB. Tactile sensibility in the human hand: relative and absolute densities of four types of mechanoreceptive units in glabrous skin. *The Journal of Physiology*. 1979; 286: 283-300.
2. Johansson RS and Vallbo AB. Tactile sensory coding in the glabrous skin of the human hand. *Trends Neurosci*. 1983; 6: 27-32.
3. Jones LA and Lederman SJ. *Human Hand Function*. Oxford University Press, USA, 2006.
4. Tiefenthaler W, Gimpl S, Wechselberger G and Benzer A. Touch sensitivity with sterile standard surgical gloves and single-use protective gloves. *Anaesthesia*. 2006; 61: 959-61.

5. Shih RH, Vasarhelyi EM, Dubrowski A and Carnahan H. The effects of latex gloves on the kinetics of grasping. *International Journal of Industrial Ergonomics*. 2001; 28: 265-73.
6. Kopka A, Crawford JM and Broome IJ. Anaesthetists should wear gloves – touch sensitivity is improved with a new type of thin glove. *Acta Anaesthesiol Scand*. 2005; 49: 459-62.
7. Mylon P, Lewis R, Carré MJ and Martin N. An Evaluation of Dexterity and Cutaneous Sensibility Tests for Use with Medical Gloves. *Ergonomics*. Forthcoming 2013.
8. Nolan CY and Morris JE. *Roughness Discrimination Test Manual*. Louisville, KY: American Printing House for the Blind, 1965.
9. Nelson JB and Mital A. An ergonomic evaluation of dexterity and tactility with increase in examination/surgical glove thickness. *Ergonomics*. 1995; 38: 723-33.
10. Brunick AL, Burns S, Gross K, Tishk M and Feil P. Comparative study: the effects of latex and vinyl gloves on the tactile discrimination of first year dental hygiene students. *Clin Prev Dent*. 1990; 12: 21-5.
11. Wilson MP, Gound S, Tishk M and Feil P. Gloved versus ungloved dental hygiene clinicians. A comparison of tactile discrimination. *Dent Hyg (Chic)*. 1986; 60: 310-5.
12. Desai S and Konz S. Tactile inspection performance with and without gloves. *Proceedings of the Human Factors Society 27th Annual Meeting*. Human Factors and Ergonomics Society, 1983, p. 782-5.
13. Skedung L, Danerlöv K, Olofsson U, et al. Tactile perception: Finger friction, surface roughness and perceived coarseness. *Tribology International*. 2011; 44: 505-12.
14. Stevens SS. Issues in psychophysical measurement. *Psychol Rev*. 1971; 78: 426-50.
15. Federation of European Producers of Abrasives. FEPA-ABRASIVES [Internet]. Paris: FEPA. P-grit sizes coated; [cited 2013 Oct 29]. Available from: http://www.fepa-abrasives.org/
16. Lewis R, Menardi C, Yoxall A and Langley J. Finger friction: Grip and opening packaging. *Wear*. 2007; 263: 1124-32.
17. Tomlinson SE, Lewis R and Carre MJ. The effect of normal force and roughness on friction in human finger contact. *Wear*. 2009; 267: 1311-8.
18. Ehrenstein WH and Ehrenstein A. Psychophysical Methods. In: Windhorst U and Johansson H, (eds.). *Modern Techniques in Neuroscience Research*. Springer, 1999, p. 1211-41.
19. Taylor MM and Lederman SJ. Tactile roughness of grooved surfaces: a model and the effect of friction. *Percept Psychophys*. 1975; 17: 23-6.
20. Derler S and Gerhardt LC. Tribology of skin: Review and analysis of experimental results for the friction coefficient of human skin. *Tribology Letters*. 2012; 45: 1-27.
21. Hollins M and Bensmaïa SJ. The coding of roughness. *Can J Exp Psychol*. 2007; 61: 184-95.

Figures and Tables

Figure 1. Stress-strain curves for two medical gloves (showing standard error).

Figure 2. Roughness Perception Apparatus.

Figure 3. Example profile of (a) P40-, (b) P180- and (c) P800-grade sandpaper.

Figure 4. University of Sheffield finger friction rig[17].

Figure 5. Example of force data from finger friction rig, showing normal load and the measured friction for (a) a latex glove on P80-grade sandpaper; (b) bare skin on P800-grade sandpaper (time and friction scales vary).

Figure 6. Dynamic COF for roughness perception samples.

Figure 7. Correlations of the specified particle size to average particle spacing and roughness average.

Figure 8. Average (geometric mean) perceived roughness in dynamic roughness perception testing of 16 subjects against roughness average (R_a) of sample.

Figure 9. Average (geometric mean) perceived roughness in static roughness perception testing of 14 subjects against average particle size of sample.

Figure 10. Relationship between perceived roughness and average particle spacing for static tests.

Table 1. Tensile stress at 200% elongation for two medical glove types.

Table 2. Sandpaper grades and particle sizes for roughness discrimination test.

Table 3. Geometric and friction measurements for roughness samples.

Table 4. Significance of differences in COF.

Table 5. Pearson correlations for roughness perception samples.

Table 6. Correlations between sandpaper geometry and geometric mean perceived roughness for each hand condition in the dynamic roughness perception test.

Table 7. Results of paired t-tests between hand conditions in dynamic roughness perception testing.

Table 8. Correlations between sandpaper geometry and geometric mean perceived roughness for each hand condition in the static roughness perception test.

Table 9. Results of paired (Wilcoxon Signed Ranks) tests between hand conditions in static roughness perception testing.