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Carré, M.J., Tan, S.K., Mylon, P.T. et al. (1 more author) (2017) Influence of medical gloves on fingerpad friction and feel. Wear, 376-7 (A). pp. 324-328. ISSN 0043-1648

https://doi.org/10.1016/j.wear.2017.01.077

Influence of medical gloves on fingerpad friction and feel

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Abstract

Friction experiments were carried out sliding a fingerpad, in both a bare state and with a latex glove donned, across a force plate to determine friction levels for different contact surface conditions (dry/wet; steel/glass). Donning a glove was found to increase the friction in dry conditions, but reduce it in wet conditions. A range of vibration frequencies were found to occur during sliding and the pronounced stick-slip behaviour for a bare finger sliding on wet glass was not found to occur when a latex glove was donned.

These frequencies, along with those measured in a previous study, were used to inform the design of a tactile vibration perception study utilising a vibrating platform to replicate the sensation of finger sliding. The use of gloves was found to reduce the amplitude threshold at which participants were able to perceive vibrations. This effect was more extreme for double glove use, compared to single glove use. Glove donning also reduced the ability of participants to perceive differences in the frequency of vibrations.

These findings have implications for surgeons' ability to carry out tactile explorations and the protocol described in this paper can be used for future studies on the effect of glove use on feel.

Keywords: Medical gloves, fingerpad friction, stick-slip, vibration perception, feel.

1. Introduction

Gloves are worn by many medical professionals undertaking a range of everyday tasks, some highly complex and often requiring good grip of instruments (Mylon *et al.,* 2014a). High levels of feedback, or "feel", are required to carry out dextrous tasks effectively, especially where task visibility is reduced, for example during dental procedures. Use of gloves could affect both grip and feedback. Recently there has been a reduction in the use of latex gloves due to allergy concerns, but some replacement gloves (e.g. nitrile) have been perceived by users to give reduced performance, particularly in the areas mentioned above (Mylon *et al.*, 2014b). Surgeons are still able to use latex gloves as a result of this. Research has been carried out on the effects of glove use on roughness, dexterity and cutaneous sensibility (Mylon *et al.*; 2015a, 2015b), along with the development of bespoke tests and protocols to simulate medical tasks (Mylon *et al.*, 2016). No study, however, has attempted to to examine the potential effect of glove use on the perception of tactile vibrations.

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The role of vibration in the tactual perception of roughness is well known (Lederman *et al.*, 1982; Fagiani *et al.*, 2011; Adams *et al.*, 2013), including how desirable the interaction is perceived to be (Barnes *et al.*, 2004) and a more recent study has measured the vibro-tactile excitations that occur due to stick-slip finger-object sliding interactions (Derler & Rotaru, 2013). The vibrations induced through sliding fingers over rough surfaces have also been replicated in previous studies, often for touchscreen applications (Konyo *et al.*, 2005; Altinsoy & Merchel, 2012).

The aim of the study was to investigate the effects of wearing gloves on: 1) friction, including the stick-slip behaviour that can occur during sliding of fingerpads; and 2) perception of the transmitted vibrations that result from fingerpad sliding, influencing tactile feedback to the wearer. For this reason, this paper will describe these two studies in two separate sections. Latex gloves were chosen as they are reported by surgeons as allowing most tactile sensation (Mylon *et al.*, 2014b). Therefore if our initial study can detect vibration perception differences between bare fingers and those wearing latex gloves, then it will be applicable for other glove designs.

2. Study of the effects of glove use on friction when sliding on flat surfaces

2.1. Materials and Methods

Friction was measured using a similar experimental set-up to Derler & Rotaru (2013) and the same apparatus, as described in a previous study by Liu *et al.* (2015). An index finger was first placed upon a test surface, mounted on a multi-component force plate (HE6X6, AMTI, dimensions 150 mm × 150 mm), capable of measuring applied forces in three orthogonal axes. The angle between the finger and test surface was maintained at approximately 40° whilst the finger was dragged along the plate causing it to slide, maintaining a near constant sliding speed of approximately 10 mm/s for the duration of each test. The sliding direction was in the same axis as the finger, towards the participant. One experienced operator (male, 23 years old) carried out all the experiments, using the same finger throughout. Force data was sampled at 1000 Hz and each friction measurement took approximately 10 s. Force measured in the opposite direction of sliding was considered to be the "Friction force", i.e. the retarding force due to friction, acting to oppose the sliding motion. Force measured in the vertical direction was considered to be the "Normal force", i.e. the load due to the finger being pressed downwards during the test. During sliding, the ratio of friction force to normal force was therefore considered to be the coefficient of friction (COF).

The index finger was either in a bare state or with a latex surgical glove (Biogel® Surgeons, Mölnlycke Healthcare) donned on the hand. Three test surfaces were used: dry steel (Ra = 0.9 µm); dry glass (Ra = 0.1 µm); and wet glass (the same surface having being sprayed with water before each test to maintain a fully wetted state). Tests were carried out over a range of normal loads from approximately 0.2. N to 5 N, with approximately 8 test runs completed for each of the six finger-surface combinations (46 test runs were carried out in total).

2.2. Results and Discussion

Figure 1 shows two typical test run datasets collected during sliding motion for the friction measurements (each containing 1000 data points for both normal and friction force). For each pair of data points, COFs were obtained and the overall COF averages and standard deviations were calculated. Variation coefficients were then produced for each COF data set (dividing the standard deviation by the average COF, in order to normalise the data). According to the study by Derler & Rotaru (2013), measured COFs with variation coefficients of less than 10 % can be considered as having arisen from “stationary sliding”, whereas variation coefficients of more than 25 % indicate true “stick-slip” behaviour. For the bare and gloved finger measurements on dry steel, the highest COF variation coefficients ranged from 5 to 11 % and 4 to 9 % respectively, indicating that true stick-slip behaviour was not set up during test runs on this surface. For the dry glass measurements, the COF variation coefficients were slightly higher, ranging from 5 to 15 % for the bare finger and 4 to 13 % for the gloved finger, suggesting that stationary sliding also dominated during test runs on this surface. Figure 1a) is an example of such a dataset: a gloved finger sliding on dry glass with an average normal force of 2.17 N, an average COF of 1.47 and a variation coefficient of 6.6 %. The region of interest that has been enlarged shows a variation in friction force, but only what would be expected due to noise-related fluctuations in the measured data. No stick-slip behaviour can be seen, as defined by Derler & Rotaru (2013).

For the wet glass experiments, different behaviour was observed between the bare and gloved finger measurements and this was reflected in statistical analysis of the data. All except one of the bare finger / wet glass data sets produced COF variation coefficients greater that the stick-slip threshold of 25 % and these ranged from 14 to as high as 50 %. Figure 1b) shows the dataset that produced the highest COF variation coefficient (50.1 %); it had an average normal force of 0.88 N, an average COF of 0.89 and shows many similarities to the “on-off” stick-slip behaviour reported for bare finger sliding on wet glass by Derler & Rotaru (2013). The enlarged region of interest shows a saw-tooth pattern in the force data, typical of stick-slip, repeating at approximately 7 Hz, containing a higher frequency, damped sinusoidal pattern. Fourier analysis of this and other similar datasets indicated the pronounced sinusoidal frequency, to be approximately 40 Hz, along with less pronounced peaking frequencies over the range 0 to 200 Hz (note: due to the sampling frequency, only frequencies up to 500 Hz could be analysed). It is possible that the sinusoidal frequency could have been enhanced by resonance effects within the experimental set-up and this will be considered further in future studies. The existence of stick-slip behaviour during the bare finger / wet glass test runs was also reinforced by audible squeaking that occurred. The gloved finger / wet glass test runs did not, however, exhibit stick-slip behaviour. COF variation coefficients for these data sets only ranged between 8 and 12 %, below the accepted threshold of 25 %. Fourier analysis of the datasets from test runs that did not exhibit stick-slip behaviour did not reveal any pronounced frequencies, but indicated vibrations occured in the range of 0 to 200 Hz. Compared to the study by Derler & Rotaru (2013), who found stick–slip oscillation frequencies as high as 1500 Hz, our experiments were carried out at a relatively slow sliding speed and this would reduce the frequencies of vibration measured.

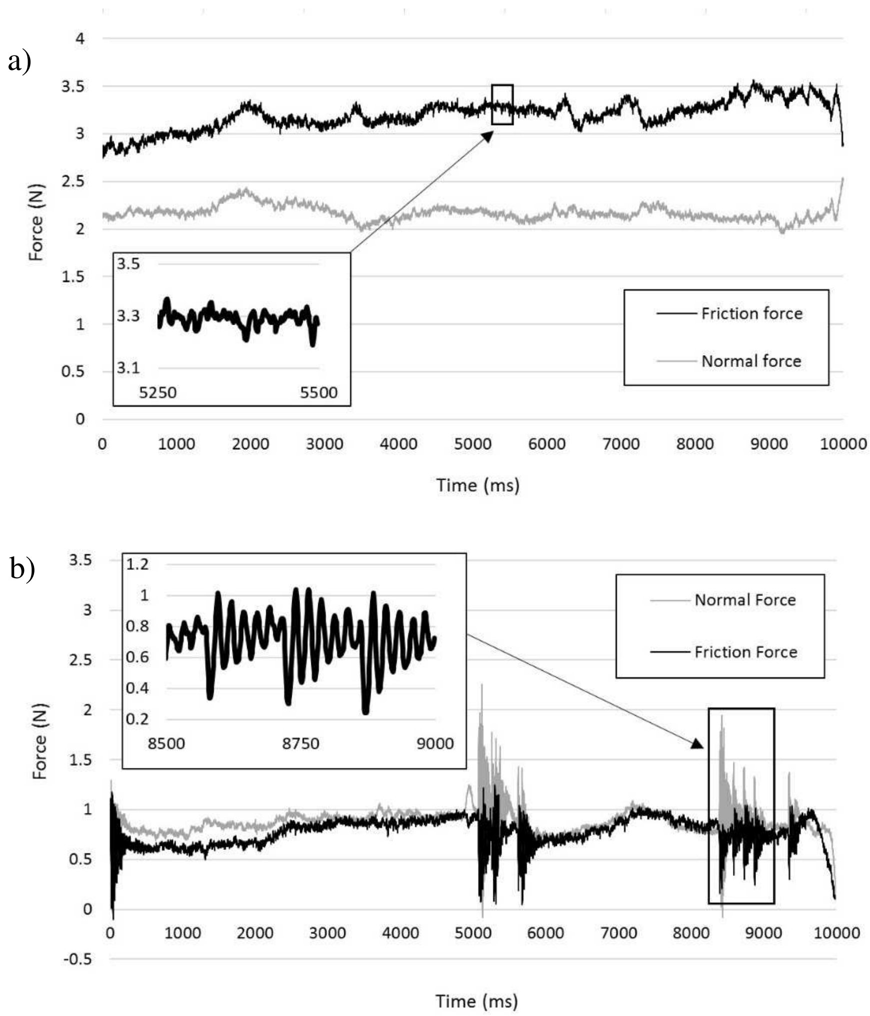

Figure 1. Example raw friction data from: a) gloved finger sliding on dry glass; b) bare finger sliding on wet glass. Regions of interest have been magnified

Following calculations of the COFs, the general friction behaviour was examined with respect to the applied normal load. For all the finger-surface combinations, a power law relationship was found; COF = $a * N^b$ (where N is the normal applied load). The same type of relationship has been widely reported in previous studies of human skin and finger pad friction (Comaish & Bottoms, 1971; Tomlinson *et al.*, 2007; Derler *et al.*, 2009). Figure 2 shows COF data for the gloved and bare finger measurements taken on dry steel. The power law relationships can be seen for both data sets. On this surface the gloved finger was found to provide higher friction than the bare finger.

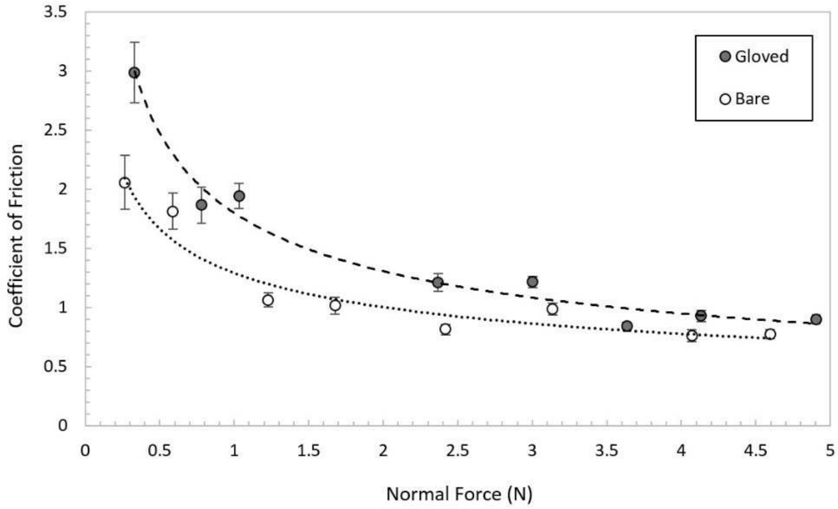

Figure 2. Friction data for a gloved and bare finger sliding on dry steel (power law fits have been added)

The calculated power law coefficients for each set of COF data were used to predict the COFs that would be found for each finger-surface condition combination, had the sliding experiments been conducted using a normal force of 1 N, a force level in the range used for precision grip and tactile exploration (Adams *et al*., 2013). This was to allow comparison between the combinations. The result of this is shown in Figure 3. For both dry surfaces, the use of a glove was found to increase the sliding friction considerably. This could be due to increased components of adhesion and hysteresis (Adams *et al.*, 2009), contributing to higher friction when a glove is donned. For smooth surfaces, a ridged finger pad has a reduced contact area, in comparison with a smooth latex rubber surface, and therefore a reduced adhesion component. In addition, a gloved fingerpad could be subject to greater shearing deformation during sliding, therefore increasing the hysteretic component.

For the wet glass surface, the bare finger was found to provide higher friction than the gloved finger. This is most likely due to the finger ridges being able to break through the lubrication film and increase contact. In a previous bare fingerpad study (Tomlinson *et al.*, 2011), other moisture-related effects such as swelling due to water absorption and therefore increased contact and friction, were discussed. The glove would act as a barrier to prevent this from happening.

It should be pointed out that, as these measurements were only carried out using one human subject, the effects of glove use may be smaller or indeed greater for other populations. However, it is clear that gloves have an effect on friction.

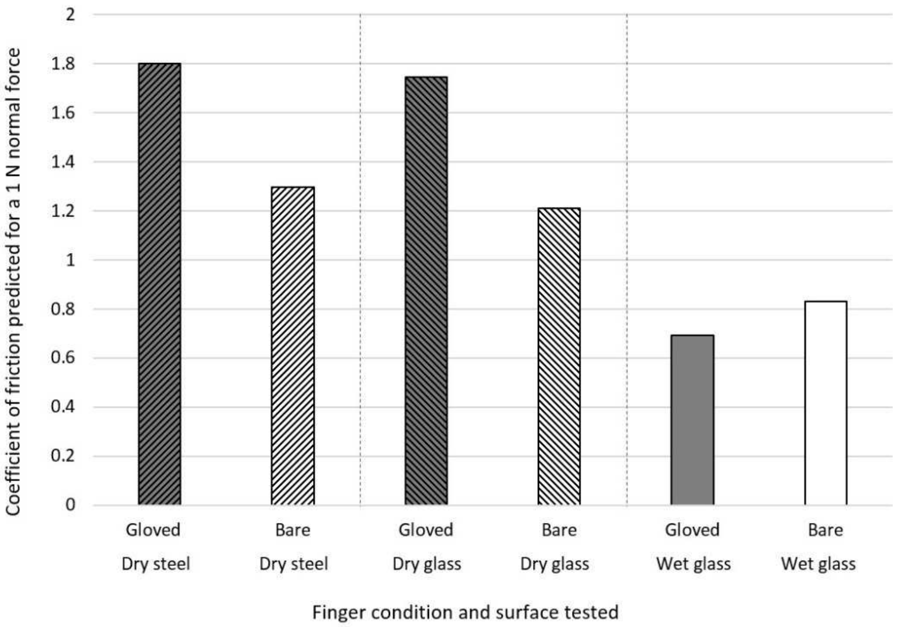

Figure 3. Coefficients of friction predicted for a 1 N normal force for all finger conditions and surfaces tested

3. Study on the effect of glove use on perception of tactile vibrations

3.1. Materials and Methods

Derler & Rotaru (2013) reported that bare finger stick-slip sliding on wet glass at sliding speeds ranging up to 1.5 m/s can generate vibrations over a large frequency range of 50 Hz to 1500 Hz and our experiments at a relatively slow sliding speed of 10 mm/s produced stick-slip vibrations at lower frequencies. However, it is generally accepted that humans are most able to sense and perceive tactile vibrations in the range 0 to 500 Hz and different mechanoreceptors are used for this purpose. Fast adapting Pacinian corpuscles are specifically for vibration sensing and in particular for sudden disturbances, such as would occur during stick-slip sliding. They can respond to vibrations up to 500 Hz. Meissner corpuscles respond well to light touching (below 1 N) and are also sensitive to vibration frequencies in the range 5 to 50 Hz. For our experiments vibration frequencies were chosen that would be picked up by Pacinian Corpuscles, so a range of 100 to 500 Hz was selected for further study. Note: experiments were carried out using both the index finger and thumb, but each gave similar results so for the sake of brevity, only the finger data is reported in this paper.

Vibrations were induced using a system that had been developed for a previous study, concerned with tactile feedback for touchscreen devices (Zhang *et al.*, 2014). The apparatus is shown in Figure 4 and consists of a small speaker, mounted on top of the force plate that was used in the friction study. The speaker can produce controlled vibration signals of different frequencies and amplitudes, set up using a commercial audio software package (Audacity v2.0.2). The participant places their index finger directly on to the speaker in order for the vibration signals to be transmitted. The vertical pressing force, as measured by the force plate, is maintained within the range of 0.5 to 1 N throughout testing; Adams *et al*. (2013) reported that tactile exploration occurs at pressing forces below 2 N. Fourteen participants, aged between 20 and 30 years old, were recruited for this study which was reviewed and approved by the Research Ethics Committee at the University of Sheffield.

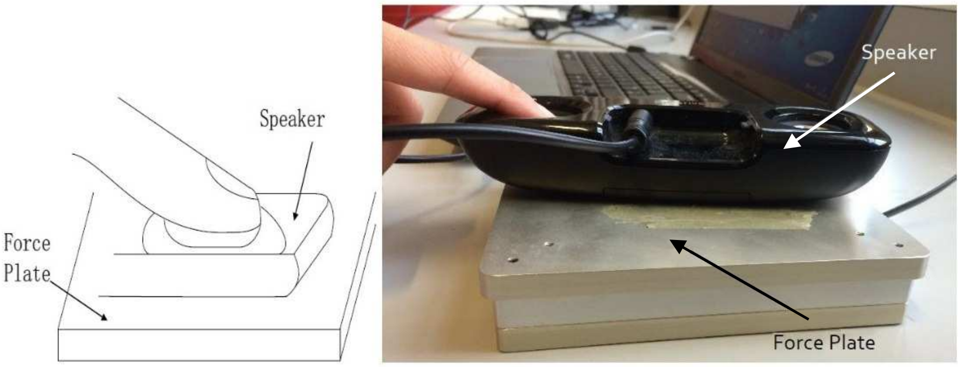

Figure 4. Apparatus used for the vibration perception experiments

Threshold for perception of vibration

The first set of experiments were designed to ascertain the amplitude threshold at which participants could perceive tactile vibrations, and the effect of glove donning. Each participant was asked to place their finger on the speaker and a vibration at 440 Hz was transmitted through the speaker for a 1 s exposure time at a benchmark amplitude level of 1 V / 54 dB. The frequency was set at this relatively high level to challenge the participants' use of their Pacinian corpuscle mechanoreceptors, with a relatively high amplitude that the majority of people would be able to perceive initially. Participants were then exposed to further 1 s duration vibrations, each at decreasing levels of amplitude, set up as ratios of the initial signal (0.8, 0.6, 0.4, 0.2 and 0.1). After each exposure, participants were asked whether they could feel any vibration. The procedure was then repeated with a single glove donned and then again using two gloves ("double-gloving" is common practice among surgeons, particularly when carrying out procedures with high risk of contamination and/or glove puncture). Finally, the entire experiment was repeated but with the amplitude ratios now increasing from 0.1 to 0.2, 0.4, 0.6, 0.8 and ending at 1.0.

Perception of change in vibration frequency

The second set of experiments were designed to ascertain how glove use effects participants' ability to distinguish vibrations of similar frequency. Participants were first exposed to 1 s duration vibrations at one of the following frequencies (125; 150; 175; 200; 225 and 250 Hz). Immediately after this, a 1 s exposure to a vibration of base frequency 100 Hz was provided. All signals were maintained at a level of 54 dB. After each pair of exposures, the participants were asked if the signals were the "same" or "different. Each pair of signals was used in a randomised order for each participant and repeated at least once to build up a sufficient data set. This range of frequencies was chosen as it fell within the central range that can be picked up by Pacinian corpuscles. The entire experiment was then repeated with single and double gloves donned.

3.2. Results and Discussion

Threshold for perception of vibration

The vibration threshold data from all 14 participants was collated and the percentage able to perceive each signal was calculated, as shown in Figure 5. Similar results were found whether the exposures were carried out in decreasing or increasing order of amplitude ratio. All the participants were able to perceive all the 440 Hz vibration signals at an amplitude ratio of 0.4 or above, regardless of whether gloves were donned. However, for ratios of 0.2 and below the use of gloves started to show an effect, as can be seen in Figure 5. Generally, single gloves reduced the percentage of vibrations perceived and double gloves reduced this even further. At an amplitude ratio of 0.1, 43 and 50 % of participants could perceive vibrations with a bare finger (amplitudes decreasing or increasing, respectively), with a single glove this reduced to 14 and 22 %, and with double gloves none of the participants could perceive this level of vibration.

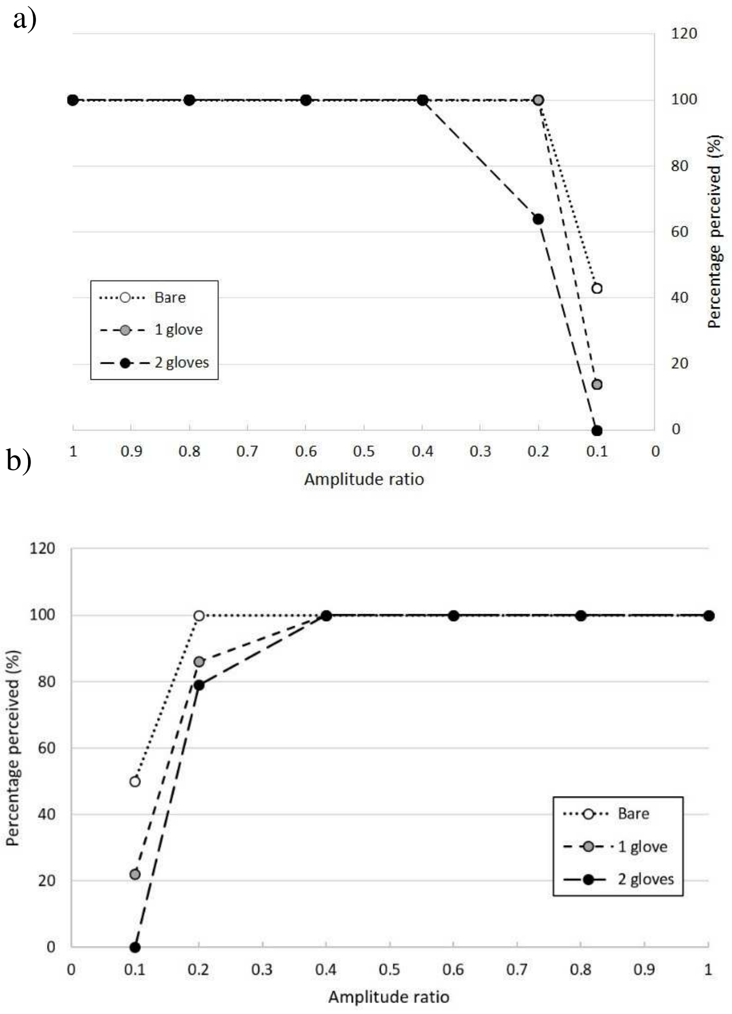

Figure 5. Percentage of vibration signals at 440 Hz perceived when: a) the amplitude ratio was decreased; b) the amplitude ratio was increased

Perception of change in vibration frequency

The data from the second set of perception experiments was collated and the percentages of vibration signals correctly identified as being different from the base frequency, are shown in Figure 6. All participants were able to correctly distinguish between signals of 200 Hz and above, when compared to the base frequency of 100 Hz, regardless of whether gloves were donned or not. At the 175 Hz level, double-gloving had a slight impact on the ability to perceive a difference in the pair of signals but all participants were able to perceive the difference if only one glove or no gloves were donned. For the signals at 150 Hz, more differences can be seen between the gloved and bare finger experiments. Over 80 % of the signal pair differences where correctly perceived using a bare finger, but this dropped to around 60 % when gloves were donned. Most participants had difficulty in perceiving a difference between the 125 Hz signal and the 100 Hz base frequency. In general, the use of gloves can be seen to impair the participants' ability to discern a difference between the frequency pairs that they were exposed to.

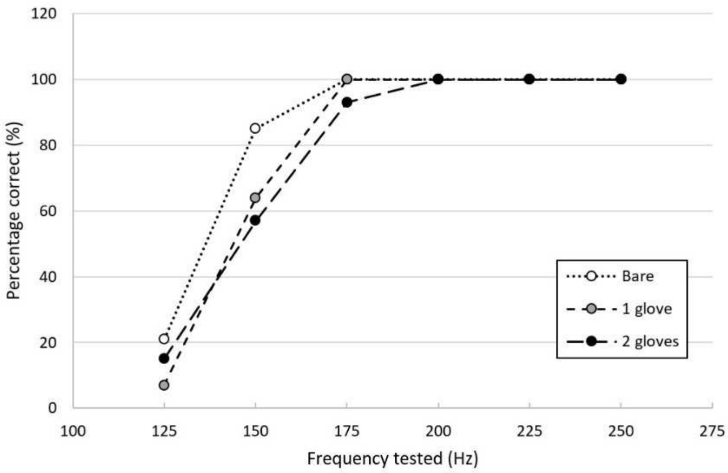

Figure 6. Percentage of index finger excitation frequencies correctly perceived when compared to the 100 Hz base frequency, under three different conditions

4. Conclusions

Sliding fingerpad friction experiments using three surface conditions (dry steel, dry glass, wet glass) showed that the use of a latex glove increased the friction in dry conditions, but reduced it in wet conditions. A range of vibration frequencies were found and the pronounced stick-slip behaviour measured for a bare finger sliding on wet glass was not found to occur when a latex glove was donned.

Perception experiments found the use of gloves reduced the amplitude threshold at which participants were able to perceive vibrations, with double-gloving having a greater effect than donning a single glove. Glove use also reduced the ability of participants to perceive differences in the frequency of vibrations.

The findings from this study have implications on the ability of surgeons to make tactile explorations and receive vibro-tactile feedback, when using gloves. The experimental protocol was found to be able to measure the effects of latex gloves. Further research is now required to see how other glove designs may affect vibration perception and the separate effects of glove parameters (e.g. material properties, thickness, fit).

5. References

Adams, M. J., Briscoe, B. J., & Johnson, S. A. (2007). Friction and lubrication of human skin. *Tribology Letters*, 26(3), 239-253.

Adams, M. J., Johnson, S. A., Lefèvre, P., Lévesque, V., Hayward, V., André, T., & Thonnard, J. L. (2013). Finger pad friction and its role in grip and touch. *Journal of The Royal Society Interface*, 10(80), 20120467.

Altinsoy, M. E., & Merchel, S. (2012). Electrotactile feedback for handheld devices with touch screen and simulation of roughness. *IEEE Transactions on Haptics*, 5(1), 6-13.

Barnes, C. J., Childs, T. H. C., Henson, B., & Southee, C. H. (2004). Surface finish and touch—a case study in a new human factors tribology. *Wear*, 257(7), 740-750.

Comaish, S., & Bottoms, E. V. A. (1971). The skin and friction: deviations from Amonton's laws, and the effects of hydration and lubrication. *British Journal of Dermatology*, 84(1), 37-43.

Derler, S., Gerhardt, L. C., Lenz, A., Bertaux, E., & Hadad, M. (2009). Friction of human skin against smooth and rough glass as a function of the contact pressure. *Tribology International*, 42(11), 1565-1574.

Derler, S., & Rotaru, G. M. (2013). Stick–slip phenomena in the friction of human skin. *Wear*, 301(1), 324-329.

Fagiani, R., Massi, F., Chatelet, E., Berthier, Y., & Akay, A. (2011). Tactile perception by friction induced vibrations. *Tribology International*, 44(10), 1100-1110.

Konyo, M., Tadokoro, S., Yoshida, A., & Saiwaki, N. (2005). A tactile synthesis method using multiple frequency vibrations for representing virtual touch. In 2005 *IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 3965-3971). IEEE

Lederman, S. J., Loomis, J. M., & Williams, D. A. (1982). The role of vibration in the tactual perception of roughness. *Perception & Psychophysics*, 32(2), 109-116.

Liu, X., Gad, D., Lu, Z., Lewis, R., Carré, M. J., & Matcher, S. J. (2015). The contributions of skin structural properties to the friction of human finger-pads. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, 229(3), 294-311.

Mylon, P., Lewis, R., Carré, M. J., & Martin, N. (2014a). A critical review of glove and hand research with regard to medical glove design. *Ergonomics*, 57(1), 116-129.

Mylon, P., Lewis, R., Carré, M. J., Martin, N., & Brown, S. (2014b). A study of clinicians' views on medical gloves and their effect on manual performance. *American Journal of Infection Control*, 42(1), 48-54.

Mylon, P. T., Buckley-Johnstone, L., Lewis, R., Carré, M. J., & Martin, N. (2015a). 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.

Mylon, P., Lewis, R., Carré, M. J., & Martin, N. (2015b). An evaluation of dexterity and cutaneous sensibility tests for use with medical gloves. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, (currently available online).

Mylon, P., Lewis, R., Carré, M. J., & Martin, N. (2016). Evaluation of the effect of medical gloves on dexterity and tactile sensibility using simulated clinical practice tests. *International Journal of Industrial Ergonomics*, 53, 115-123.

Tomlinson, S. E., Lewis, R., & Carré, M. J. (2007). Review of the frictional properties of finger-object contact when gripping. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, 221(8), 841-850.

Tomlinson, S. E., Lewis, R., Liu, X., Texier, C., & Carré, M. J. (2011). Understanding the friction mechanisms between the human finger and flat contacting surfaces in moist conditions. *Tribology Letters*, 41(1), 283-294.

Zhang, X., Carré, M., & Rowson, J. (2014). Effect on Frequency Changing of Tactile Feedback on Touchscreen Devices. *Design 4 Health 2013 3-5 July 2013, Sheffield, UK*, 316.