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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.

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 [12]. 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 [13]. 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 [14,15], along with the development of bespoke tests and protocols to simulate medical tasks [16]. No study, however, has attempted to examine the potential effect of glove use on the perception of tactile vibrations.

The role of vibration in the tactual perception of roughness is well known [10,2,8], including how desirable the interaction is perceived to be [4] and a more recent study has measured the vibro-tactile excitations that occur due to stick-slip finger-object sliding interactions [7]. The vibrations induced through sliding fingers over rough surfaces have also been replicated in previous studies, often for touchscreen applications [3,9].

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 [13]. 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 and Rotaru [7] and the same apparatus, as described in a previous study by Liu et al. [11]. An index finger was first placed upon a test surface, mounted on a multi-component force plate (HE6 × 6, 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

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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

Fig. 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 and Rotaru [7], 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

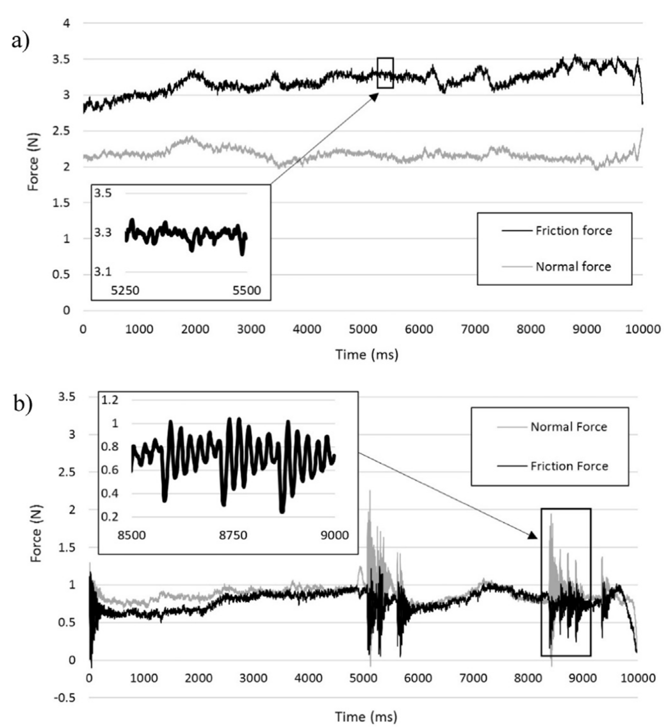

Fig. 1. Example raw friction data from: a) gloved finger sliding on dry glass; b) bare finger sliding on wet glass. Regions of interest have been magnified.

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. Fig. 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 and Rotaru [7].

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%. Fig. 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 and Rotaru [7]. 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 occurred in the range of 0 to 200 Hz. Compared to the study by Derler and Rotaru [7], 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.

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; $\text{COF}+a^*N^b$ (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 [17,5,6]. Fig. 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.

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 [2]. This was to allow comparison between the combinations. The result of this is shown in Fig. 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 [1], contributing