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Preece, D., Lewis, R. orcid.org/0000-0002-4300-0540 and Carré, M.J. (2020) Effects of Mucin on the dexterity and tactile sensitivity of medical glove users. Biotribology, 24. 100146.

https://doi.org/10.1016/j.biotri.2020.100146

Effects of Mucin on the Dexterity and Tactile Sensitivity of Medical Glove Users

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Evaluation of the Effects of Mucin on Medical Glove Users Dexterity and Tactile Sensitivity

The evaluation of medical glove performance has mostly focused on analysing how good a barrier the glove materials are, as well as their durability. Very few studies aim to determine how these gloves affect the performance of the user. This could lead to a lowered ability to carry out tasks, leading to poor healthcare due to diminished sensitivity and dexterity. Furthermore, none of these studies incorporate contaminants to replicate the real-world environments in which medical gloves are used. The work carried out here aims to look at the effects of the bodily fluid mucin on medical glove user's performance. This was assessed via the use of the Purdue Pegboard and Crawford Small Parts Dexterity Test in conjunction with a tactile bump sensitivity test. These tests were carried each in five conditions; bare hand, donned natural rubber latex (NRL) and donned acrylonitrile butadiene rubber (XNBR) gloves – both with and without a 10mg/ml concentration of porcine gastric mucin applied. The results show that donning gloves decreased dexterity and sensitivity compared to the bare hand. However, mucin was shown to increase dexterity and sensitivity in XNBR, but not with NRL. This is expected to be due to the different ways in which the materials interact with the mucin, affecting the ability to develop a muco-adhesive film and changing the frictional properties of the glove materials.

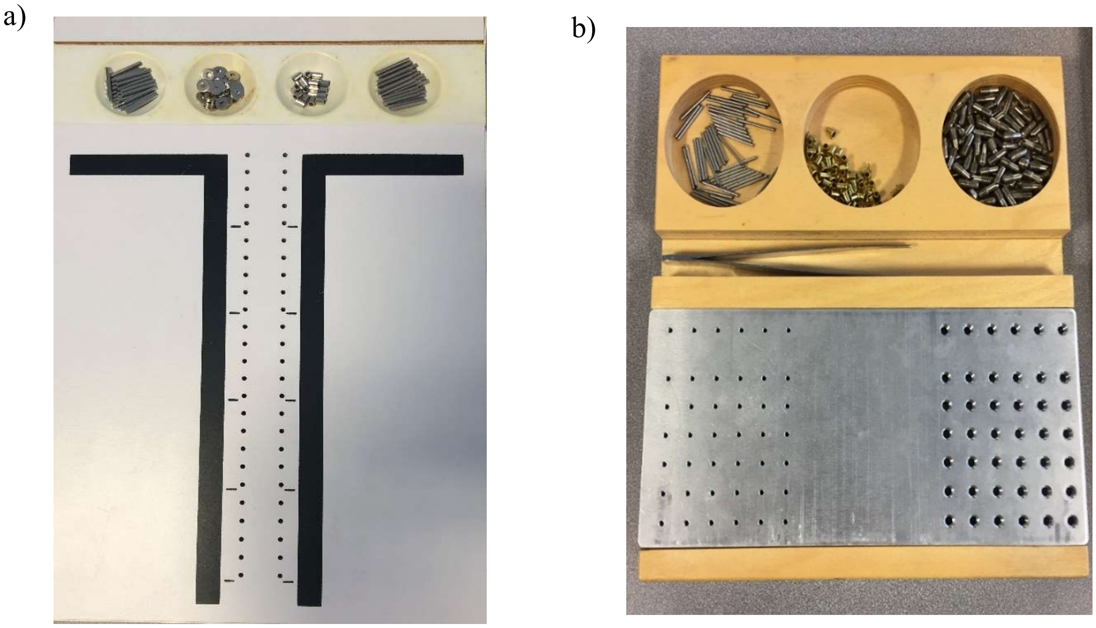
Keywords: medical examination gloves; Sensitivity; Dexterity; Latex; Nitrile; Tribology

Funding

This research was fully funded by the Engineering and Physical Science Research Council (EPSRC) though the integrated Tribology Centre for Doctoral Training (iT-CDT) and sponsorship by Synthomer (UK) Ltd.

1. Introduction

The use of pegboard tests to assess dexterity is well documented [1, 2]. These boards have the aim of assessing motor skills for the rehabilitation of patients or assessing finer dexterity for industrial applications. Their use, however, has become more widespread and they are employed for assessing the effects medical gloves have on users. Much of the research regarding the effects of dexterity utilises the Purdue Pegboard test (Figure 1a) and the Crawford Small Parts Dexterity Test (CSPDT) (Figure 1b). Both involve the assessment of hand-eye coordination and motor skills of participants through the placement of pins into holes and adding collars/washers depending on the test being conducted. Generally, reviews indicate that there is no significant effect on dexterity when gloves are worn, although in some cases, there are observable differences [1-3].



Figures 1a-1b. a) Purdue Pegboard and b) Crawford Small Parts Dexterity Test (CSPDT). These two tests are commonly used throughout the literature for assessments of glove materials with regards to dexterity.

Similarly, when it comes to tactility, tests have been adapted by incorporating medical glove materials to assess the loss of sensation when the rubber membrane is placed over the skin. The ability to sense and identify pressure, bumps, lacerations, foreign objects and tears is paramount to a medical practitioner [4]. Changes in stimuli on the skins surface arise as a result of frictional signals created by skin-surface contact. This contact stimulates skin surface strains, propagating to the mechanoreceptors in the skin. These mechanoreceptors are sensory cells that respond to changes in stimuli through pressure on the skin, allowing people to feel surfaces [5]. They also play a vital role in avoiding slipping when manipulating objects as well as providing feedback on changes in surface textures [6]. If tactility is dampened, this could lead to incorrect patient care through missed information (e.g. a missed tumour or internal laceration) or dropped equipment. Many of the tactility assessments apply the mono-filament test, in which nylon filaments of varying cross-sectional diameter are pressed onto the skin to elicit a sensation [7]. Another conventional assessment is the two-point discrimination test which looks at the ability of participants to feel two separate points of pressure on the skin. The results of most of these tactility tests conclude that tactile response decreases when gloves are worn [2, 3]. Typically, these tests are static methods of tactile analysis, as the equipment is placed on the skin to evoke a nervous response. Researchers have also developed tests to try to obtain measurable differences between glove materials through discriminatory tests [8]. These tests tend to have more dynamic approaches as the fingers move over areas to explore surface anomalies (such as bumps) or different textures [9]. Examples of such tests are the two Simulated Medical Examination Tactile Tests (SMETTs) developed by Mylon *et al.* [10]. These tests were developed to assess the ability of participants to 1) press and feel pegs of varying heights (2.5-14.5mm) embedded in silicone; and 2) stroke and feel for varying sized bumps (100-600µm in height) that have been 3D printed as a rigid tile. Although these tests are a better representation of the real-world conditions (i.e. feeling for bumps under a surface) than the monofilament or two-point discrimination tests, a flaw, noted by the author, is that the participants either placed their fingers flat onto the tests, or at an angle. Deviations in the orientation of fingers have been shown to give very different perceptions of feeling due to the dispersion of mechanoreceptors in the skin [4].

When it comes to assessing medical gloves, it is important to consider the reason as to why medical gloves are donned. That is, to protect the users from contamination. Laroche *et al.* [11] included water to measure the static friction of medical gloves with different surface patterned tools. To date no literature has been found which seeks to integrate any kind of contaminant, such as fluids, into the performance tests. In order to assess medical gloves for real-world applications, real-world contaminants need to be factored into these assessments. A major fluid found throughout the body is mucin, a viscoelastic central component of mucous, found in saliva, and the linings of the respiratory, urinogenital, and gastrointestinal tracts [12]. Composed of long peptide chains, mucins are of a characteristically high molecular mass owing to the abundance of hydrophilic carbohydrate side chains that span off the central protein. Due to this size, and hydrophilicity of the carbohydrates, charge repulsion enables the protein to entangle and form muco-adhesive gels. When the water evaporates from the gel, a thin muco-adhesive film is left behind, known as a tribo-film [13]. Given the limited research on the impact of contaminated medical gloves on user performance, the aim of this study was to evaluate the effect mucin has on the dexterity and tactile sensitivity of participants wearing two types of common medical glove materials.

2. Materials and methods

All test protocols, participant consent and information forms were submitted to, and approved by, The University of Sheffield Research Ethics Committee.

2.1. Participants

A total of 12 participants took part in the sensitivity test (2 females and 10 males) and 15 participants took part in the dexterity tests (2 female and 13 males). All of the participants were volunteers from The University of Sheffield and were aged between 22 and 34 years. The participants all reported to have no sensorimotor deficiencies or any conditions that could be related to such deficiencies.

2.2. Glove Selection

Two glove materials were used in this study: acrylonitrile butadiene rubber (XNBR) provided by Synthomer Ltd. and natural rubber latex (NRL) gloves, supplied by Safetouch and purchased commercially. Both gloves were chlorinated and contained no powder inside. Glove thickness (t) was measured using a micrometer (Mitutoyo, quickmini) and was found to be the same for both glove types at the palm (0.10mm) and fingertips (0.11mm). The XNBR gloves were shown to have a textured pattern at the fingertip, whereas the NRL gloves had a non-structured rough surface all over (Figure 2). Glove surface roughness (Sa) at the fingertips was found to also be similar for both gloves (XNBR Sa = 1.90µm; NRL Sa = 1.83µm) determined by using Alicona optical 3D measurement. Glove size was self-selected by participants based on their perceived 'best-fit'. The medium glove size was the best-fit choice for all participants with both materials, except for two who required large XNBR, but were comfortable with medium NRL.

Figure 2. Patterns on XNBR (left) and NRL (right) gloves used in this study.

2.3. Mucin Solution

Mucin was chosen due to the abundance in the body, making it a likely source of contamination for medical gloves [13]. Porcine gastric mucin (Type II, un-purified) was heated to physiological body temperature (37°C) via a water bath whilst in use. The solution was purchased commercially and prepared un-purified at a concentration of 10mg/mL using deionised water, giving a pH similar to that found in the body (7.4). Specifically, porcine gastric mucin has been observed to display similar behaviour and viscosity to human mucin [14, 15]. At 10 mg/mL, the viscosity of mucin is around 3.1 mPa^{-s} at 37°C and displays a non-Newtonian behaviour, where viscosity reduces in response to an increase in shear rate [15, 16].

2.4. Purdue Pegboard test

The Purdue Pegboard, as described in Tiffin and Asher [17], is comprised of a board containing 25 holes on either side (Figure 1a). At the top of the board lie concave dishes holding metal cylindrical pins in the outer left and right dishes. The innermost middle two dishes hold collars on the left and washers on the right. There are two parts to this test, the first is the combined test which requires participants to determine how many pins they can place into the holes using their left hand, right hand and both hands in each for 30 seconds. The sum of the scores was added to form an overall score, with the 'both hands' condition being the number of pairs placed. The second test measured a finer level of dexterity, which allowed participants one minute to assemble as many pin-washer-collar-washer structures as possible. The assembly of one structure had to be completed before moving onto the next. A total score was obtained from the parts of the structure assembled.

2.5. Crawford Small Parts Dexterity Test

The CSPDT has been previously described by Crawford and Crawford [18]. This test originally consisted of two parts: pin and collar placement and screws placement, each consisting of 36 holes. For this experiment, only the pin and collar placement section of the test was focused on. This test required participants to place pins into the board and place a collar on top using tweezers. Due to time restraints, participants were required to fill only half of the board (n=18). The test was scored by the time taken to complete the required number of assemblies.

2.6. Bumps Sensitivity Test

Described by Mylon *et al.* [10], the bumps test comprised an elastomeric sheet which is integrated into a plastic holder with a guide attached; aimed to guide the finger over a column of the test bed (Figure 3). The elastomer has 26 bumps manufactured on the surface starting at 100µm in size and increasing by 20µm, up to 600µm. A light dusting of talcum powder was used, as in the original study, to reduce friction of the soft rubber-elastomer contact surfaces. Participants were instructed to place their fingers on the board within the guide, run their finger down and verbally indicate if they perceived any bumps. Participants were able to explore at their own pace and run the finger up and down to explore the area and indicate when they would like to move on to the next column. All of the columns were used for each test and participants were informed of the requirement to keep their finger flat on the board and look away or close their eyes as they did the test because the bumps become visible when the talcum powder is present. Although all of the columns were used in each condition, column placement was varied each time in order to limit the learning of the bump locations.

Figure 3. Simulated Medical Examination Tactile Test: Bumps test bed developed by Mylon *et al.* [10].

2.7. Mucin Application

To apply mucin to the glove materials, participants dipped their gloved fingers into the solution to around the knuckle in order to cover all of the digits. This was held in the solution for 10 seconds and removed. The mucin was then rubbed over the palm, using the dipped fingers of the same hand to ensure coverage around all fingers and the palm. Excess mucin was shaken off of the glove to prevent excess dripping over the tests. To assess differences in the amount of mucin attaching to each glove type, a preliminary experiment was carried out to measure the weight of mucin transferred to the gloves. A total of 10 of each glove material and size were weighed and two participants (both best-fit medium sized hands) donned half of each type/size and applied mucin using the procedure described. Gloves were then removed and weighed using a 5 point analytical balance (Analytical Sartorius, ±0.0001 g). The weight of mucin determined to be on the gloves is shown in Figure 4. Medium sized NRL gloves averaged a deposit of 0.49g (±0.026) of mucin, whereas larger gloves averaged 0.52g (± 0.056). Mucin on the medium XNBR weighed, on average, 0.60g (±0.067), whereas on the large, mucin weighed 0.62g (±0.025).

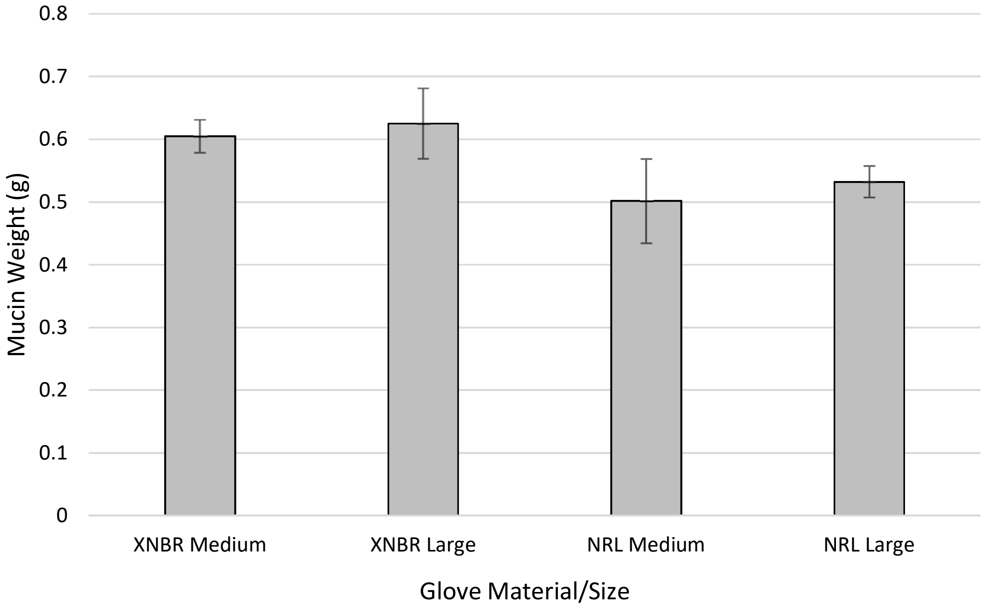


Figure 4. Mucin adherence to medium and large sized NRL and XNBR glove materials.

2.8. Learning behaviour

Participants were asked to practice the dexterity tests. These were timed and scored as real tests in order to establish a plateau in the result, before going on to conduct the actual test. The range of practice tests varied from 8-12 between participants. To minimise the possible effects of further learning behaviour throughout the dexterity tests, participants were asked to repeat tests to check for differences with their earlier result. For example, once a participant had completed a test, they were asked to repeat it, rather than moving onto the next condition. The test repeats were conducted on the third or fourth test (near the end of their 5 conditions) for each participant. The repeats were randomly assigned prior to the experiment being conducted. With the repeated test results during the experiment, the first score was used in the data analysis if the results were different upon repetition.

2.9. Experimental Design

Tests were performed in one 2-hour session with time for resting in between to avoid fatigue. Breaks were provided if and when requested. Each of the four tests (Purdue Pegboard combined and assembly, CSPDT, and bumps sensitivity tests) were carried out with bare; NRL, NRL + mucin, XNBR and XNBR + mucin. The order of tests conducted, and hand test conditions were made to be different for each participant, as suggested in Watson *et al.* [19]. Participants were also not informed of the materials being used and packaging was removed prior to glove selection. However, due to the common colour variation between materials, some participants were aware of which materials they were using. Tests were carried out at The University of Sheffield with a room temperature between 21.0-24.3°C. To eliminate the possibility of contaminants, the pegboard pieces and the tweezers were cleaned and dried between all tests using acetone and water. Participants were also asked to clean and dry their hands (using soap and water) 10 minutes before the bare hand test was conducted.

2.10. Statistical analysis

Gloving conditions were compared to each other to check for statistically significant differences within the raw data. Each set of data was checked for normal distribution using the Shapiro-Wilk Test for normality. Where the null hypothesis of normality was not rejected within the data, statistical analysis was carried out using one-way Analysis of Variance (ANOVA) followed by a post-hoc Tukey (Honestly Significant Difference) (HSD) where applicable [20]. Where the dataset was rejected for normal distribution, the non-parametric Kruskal-Wallis test was conducted followed by a Dunn's Multiple Comparison test to assess where any significant difference occurs, if applicable [21]. The null hypothesis is that the mean result of each condition should show no difference between the two compared tests. Statistically significant differences are shown at $p<0.05$. Data has been normalised in the results for easier visualisation of the differences in results, where this has occurred, statistical significance has been calculated from the original (un-normalised) dataset.

3. Results

3.1. Purdue Pegboard Test: Left, Right and Both Hands (Combined Test)

The results of the combined Purdue Pegboard test are shown in Figure 5. Data has been normalised against the bare hand condition (normalised = glove score - bare score) to highlight differences between gloving conditions. Participants placed, on average, 2.2 (±2.28) less pins with XNBR gloves when compared to bare handed condition. On the other hand, NRL decreased pin placement by 0.83 (±4.94). When mucin was added to the gloves, the results show that the average pin placement increased beyond that of the bare hand with the XNBR gloves (1.87 ±3.83), but decreased with NRL 2.2 (±2.98). The Shapiro-Wilk test found the data to be normally distributed throughout the 5 conditions, thus ANOVA tests were conducted, which shows statistically significant differences within the data ($p=0.007$). Post-hoc Tukey HSD tests show significant differences are present between XNBR and XNBR when mucin is applied ($p=0.012$) and XNBR and NRL when mucin is applied to both sets of gloves ($p=0.013$) (Table 1).

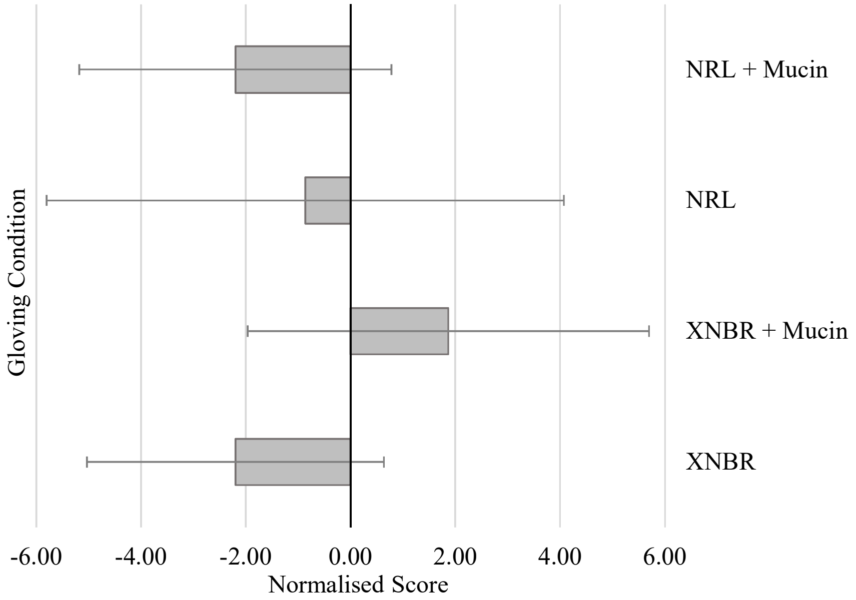


Figure 5: Normalised (glove score - bare) Purdue Pegboard test results assessing gross dexterity with the combined left hand, right hand and both hand scores.

Table 1: Tukey HSD test results for the different gloving conditions in the Purdue Pegboard combined hands result.

Condition	XNBR	XNBR + Mucin	NRL	NRL + Mucin
Bare	0.383	0.542	0.9	0.384
XNBR		0.012*	0.786	0.9
XNBR+ Mucin			0.179	0.013*
NRL				0.786

**Indicates statistical significance (p<0.05)*

3.2. Purdue Pegboard Test: Assembly Test

Some participants commented on the loose-fitting nature of the XNBR gloves. This was only revealed after attempting the assembly tests, no mention was made in the combined tests. Where this occurred, the test was stopped, and the glove was adjusted to be taught at the fingertips or changed to a new glove and the test started anew. The normalised results of the assembly portion of the Purdue Pegboard test are displayed in Figure 6 (normalised = glove score – bare hand score). This shows that all gloving conditions reduced dexterity when compared to the bare condition. The placement of the assembly components with dry XNBR led to an average decrease of 4.6 (±4.40) components when compared to the bare condition, and the dry NRL decreased assembly components by 3.33 (±7.09) on average. When mucin was added, assembly components increased with XNBR (-3.00 ±4.42) and decreased with NRL (-7.6 ±5.62). The Shapiro-Wilk test found the data to be normally distributed in 4 of the 5 conditions. Thus, ANOVA was conducted, which shows statistically significant differences in the data (*p=0.007)*. The post-hoc Tukey HSD test reveals differences between only the bare hand and the NRL glove when mucin was applied (*p=0.002)* (Table 2).

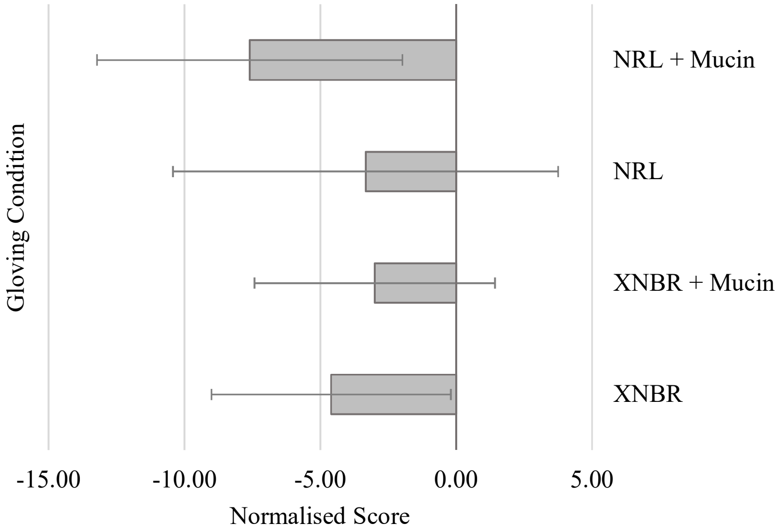


Figure 6. Normalised (gloving score - bare score) fine dexterity results from the assembly part of the Purdue Pegboard test.

Table 2: Tukey HSD test results for the different gloving conditions in the Purdue Pegboard assembly test.

Condition	XNBR	XNBR + Mucin	NRL	NRL + Mucin
Bare	0.15	0.55	0.453	0.002*
XNBR		0.9	0.9	0.55
XNBR+ Mucin			0.9	0.15
NRL				0.209

**Indicates statistical significance (p <0.05)*

3.3. CSPDT

The normalised (gloved time – bare hand time) results from the CSPDT show that when XNBR gloves were donned there was a 1.8 (±20.34) second decrease in the time taken to complete the task (Figure 7), indicating an improvement in performance. This decreased on average by 17.04 (±19.9) seconds when mucin was applied. NRL gave a decrease of 4.8 (±22.56) seconds which, when mucin was applied, further decreased by 8.2 (±21.11) seconds on average. All of the five conditions showed a significant deviation from normal distribution when using the Shapiro-Wilk test. Therefore, the Kruskal-Wallis test was conducted, which shows statistically significant differences in the data (*p=0.045*). Dunn's post-hoc tests were therefore carried out, the results of which are displayed in Table 3. This analysis shows the significant differences to be between the bare hand with XNBR and mucin (*p=0.009)*, and between XNBR and XNBR when mucin has been applied (*p=0.008)*.

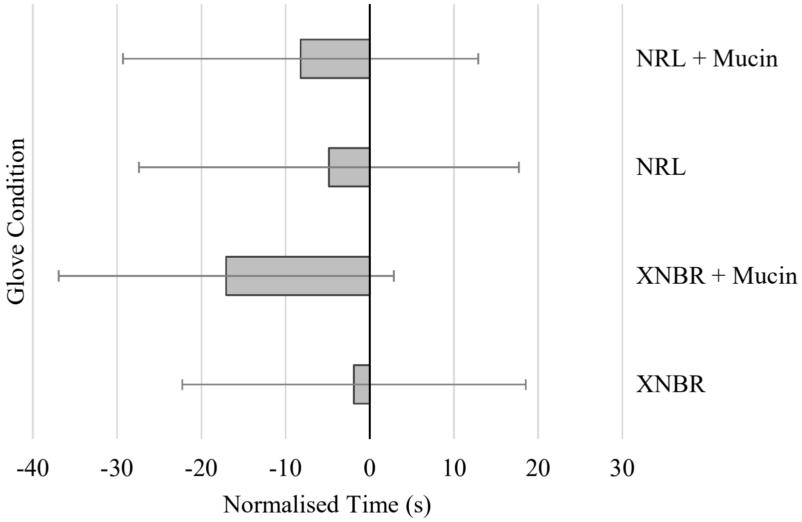


Figure 7. Normalised (gloving time - bare hand time) fine dexterity results from the CSPDT test. It should be noted, that as the score of this test is regarding time. Thus, an increase in time would denote a poor performance.

Table 3: Dunn post-hoc test results for the different gloving conditions in the CSPDT results.

Condition	XNBR	XNBR + Mucin	NRL	NRL + Mucin
Bare	1	0.009*	0.392	0.168
XNBR		0.008*	0.382	0.16
XNBR+ Mucin			0.074	0.209
NRL				0.595

**Indicates statistical significance (p <0.05)*

3.4. Bumps sensitivity

One participant only identified grooves running parallel between B and C as well as F (highlighted in Figure 8). These are not part of the test and presumed to be a fault in the manufacturing process. These grooves were noted by some of the other participants; however, they were also able to identify the bumps intended to be sensed. Another participant did not identify any bumps in any of the conditions. The data for these two participants has been eliminated from the analysis.

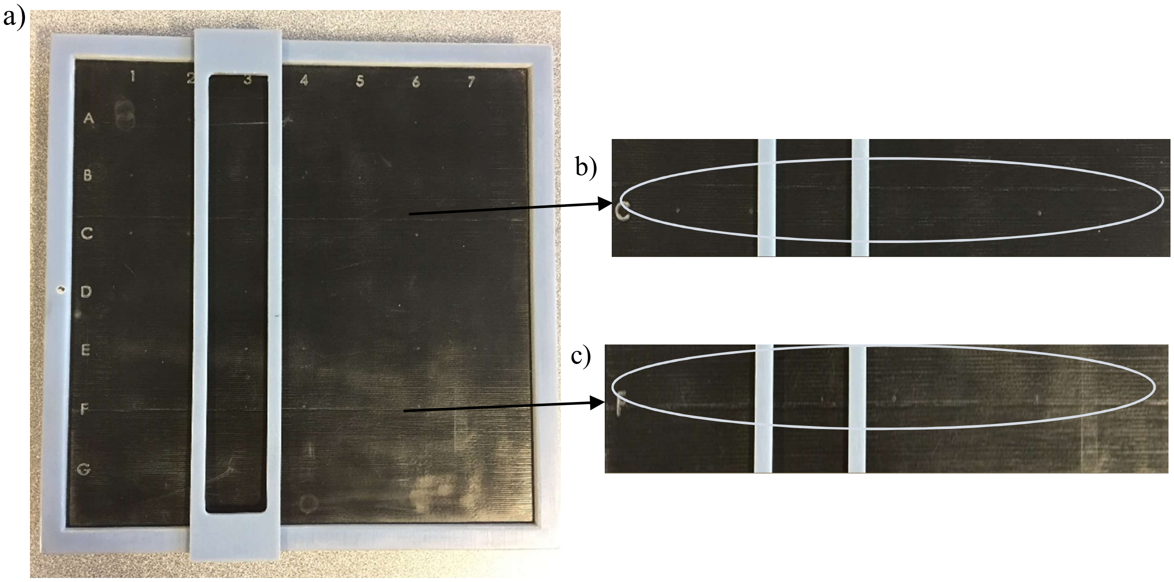


Figure 8a-8c. Groves horizontal to the board. 8a) bumps test bed. 8b) groove running across between rows B and C, and 8c) groove running across row F.

Participants (n=10) detected all bumps from 600µm down to 360µm throughout the gloving conditions. With the bare hand, the limit of detection (LOD) ranged from 180-280µm between participants. Figure 9 shows the percentage of bumps detected in each gloving condition plotted for each bump size. With the bare hand, participants felt bumps down to 180µm, giving an average detection of all bumps at 75.2%. Of the donned gloves, NRL showed a better detection rate (68%) when compared to XNBR (58%). When mucin was applied, the detection rate for XNBR increased to 62% whereas the NRL detection rate decreased to 62%.

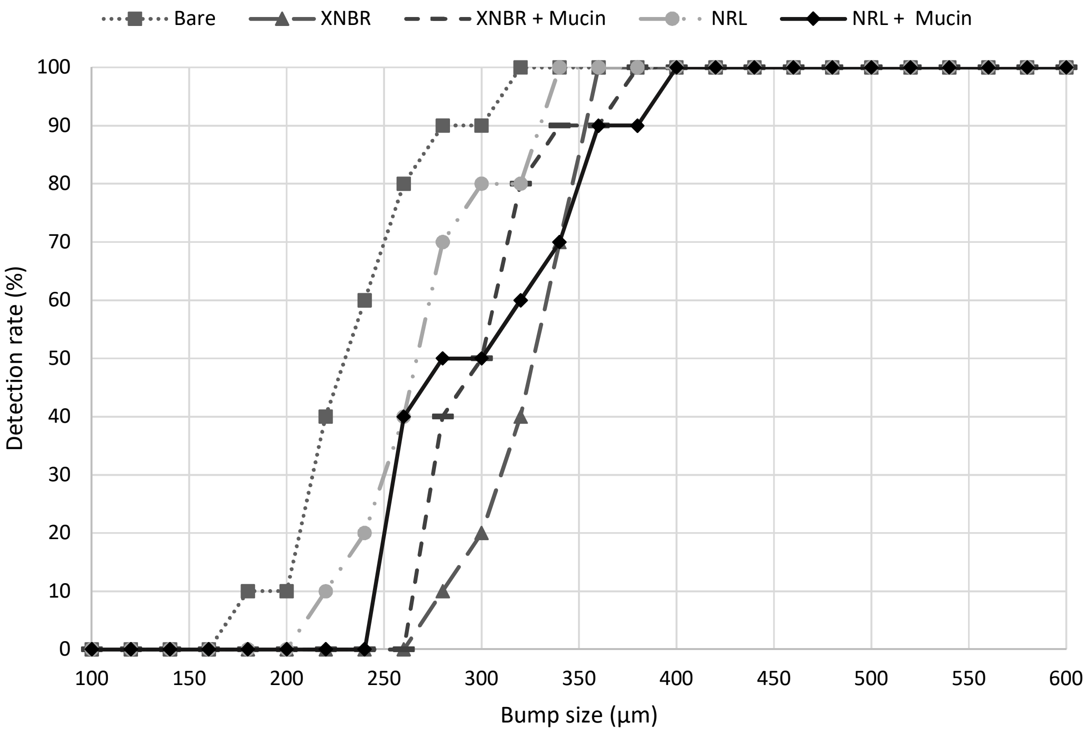


Figure 9. Results of bumps sensitivity test showing the percentage (%) detection rates at each bump size.

4. Discussion

The results of this study show that XNBR and NRL gloves do have an influence on dexterity when dry in the assembly test. The other tests do not show a great difference in performance when gloves are used. In the pegboard tests, XNBR adversely affected dexterity, decreasing the performance time when comparted to the bare hand. When NRL was donned, performance was better than the XNBR on average, but still performed worse than bare hand. However, no significant differences were found between the gloves or between the gloves and the bare hands, indicating the effects on dexterity are insignificant. None of the gloves offered an improvement to the bare condition in the fine dexterity (assembly) section of the Purdue Pegboard test. As stated previously, some of the loose material was trapped in the assembled parts causing issues with dexterity. Smaller glove sizes were tried-on by the participants, but these were either too small to be donned or too tight on participants hands. The CSPDT tests showed that the dry glove performance was not significantly different to the bare hand or to each other, although improvements in overall time taken to complete the tasks was observed. When the XNBR gloves were donned, the task was conducted on average 1.88 seconds quicker to complete when compared to the bare hand. When the NRL was donned, the task was, on average, 4.8 seconds quicker to complete, indicating a better performance when the XNBR, however the results show no statistical significance ($p>0.05$).

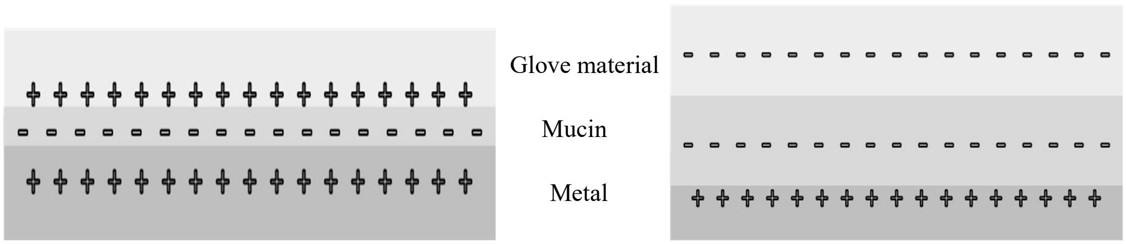
These results are similar to the results produced other tests using the Purdue Pegboard and CSPDT [22].

When mucin was present on the gloves, a difference in performance was evident. In the Purdue Pegboard combined scores, XNBR + mucin showed a statistically significant increase in the number of pins placed by the participants when compared to dry XNBR (*p=0.012*) indicating an improvement in dexterity. This improvement was also evident in the CSPDT also, as when mucin was applied, the task was conducted 17.04 seconds quicker on average, when compared to the bare hand. When applied to NRL, the mucin showed a decrease in dexterity in the Purdue Pegboard test, but improved dexterity in the CSPDT. There is a significant difference between the results in the combined pegboard test where the mucin decreased dexterity with NRL, but significantly increased dexterity with the XNBR material (*p=0.013).* The assembly test proved to be more difficult when the mucin was present, and participants noted more difficulty in their ability to carry out the task when using NRL. The bumps test showed that when gloves were donned, there was a decrease in tactile sensitivity. Mylon *et al.* [10] observed that XNBR had a higher detection rate than NRL, whereas this study presents an opposite result. The difference in participant number (32 V.S 10) could be a reason for the difference in results. However, in the previous study the thickness of the XNBR material was less than that of the latex (XNBR = 0.074 mm, NRL = 0.123 mm). As thickness has been shown to adversely affect glove dexterity and sensitivity, this could explain the differences in the results between these two studies [23]. Thus, it could be argued that a better comparison can be drawn from this study, due to the gloves being of similar thickness. Another reason could be the standardisation of finger orientation used in this test. In the previous study, participants were not instructed on how to place their fingers onto the test bed. Having the fingers flat on the surface could, as previously stated, induce more accurate results through an increase in surface contact area and activation of mechanoreceptors [24, 25]. The addition of mucin increased the detection of bumps by 4% in the XNBR gloves, but decreased detection in the NRL gloves. Overall, of the gloving conditions, the NRL gloves gave a better sensitivity allowing participants to feel down to 220µm.

4.1. Mucin-glove interaction

Where mucin was present in these tests, it is likely that the viscosity and protein conformation would have changed through manipulation and shear stress [15, 16]. This would have an effect on the lubricating or adhesion properties of the mucin solution. Higher shear rates in a system have been shown to potentially elongate the mucin polymer chains [12], as well as making them more ordered. The environment sensitive protein will change viscosity upon contact with the different materials and exhibit shear thinning with an increasing shear rate [26, 27]. This change in viscosity and overall perception of the task may have had an impact on the performance through a change in frictional properties.

Previous studies have shown the development of mucoadhesive films on surfaces which are a result of the protein folding in, reacting with itself and loosing water. This film development depends on the environmental conditions, such as temperature and interaction, as well as the viscosity and shear [12, 26, 28]. Together, the viscosity of the mucin along with film development can make for more adhesive properties when handling the equipment [29]. Participants will have varied the force applied to the tweezers, pins, and washers/collars with different gloves, changing the mucin properties through manipulation and handling, which could account for some of the differences in these results. Electrostatic interaction will also impact the frictional performance between gloves. Although these glove polymers only possess a slight charge on the surface, contact can increase the charge potential when the surfaces are in connection. However, this effect is highly unpredictable [29]. Due to the mass of negatively charged carbohydrate side chains surrounding the central peptide protein, the overall charge on mucin is generally negative at physiological pH [30]. XNBR encompasses a positive surface charge, with more polar characteristics, whilst NRL possess a negative surface charge with non-polar characteristics [29, 31]. The electrostatic interaction of these materials will affect the adhesive and lubrication properties of the mucin protein as the protein structure changes in response to the environment [28]. Two mechanisms of electrostatic interaction can occur in this particular case. Mucin will contort itself to create mucoadhesive films, based on electrostatic interactions with the environment [12, 26]. As the overall charge of mucin will be negative, the strength of the negative charge is expected to be more dominant and so more likely to take electrostatic effect. Thus, when in contact with a surface possessing a strong positive charge, the protein will migrate the negative charge to interact with the positive surface, leaving the positive regions open on the protein surface, which is shown in oral tribological work regarding mucin [32, 33]. When interacting with surfaces which have slight charges, such as is the case here, there is likely to be a similar effect, but to a much lesser extent. Figure 9 shows the hypothesised electrostatic attraction happening when participants are contacting mucin and then the metal surfaces.


(a) XNBR

(b) NRL

Figure 9. (a) Proposed representation of the attraction of charges between mucin-steel and mucin-XNBR and (b) mucin-NRL (9b). The charges on the XNBR material pull towards the mucin and the mucin also pulls towards the metal.

Figure 9a shows that the negatively charged mucin will be attracted to both the positively charged XNBR and the positively charged metal [34] as the charges on these surfaces are weaker. This would bring the two surfaces closer together, increasing the friction, allowing better grip and improving dexterity. On the other hand, NRL (Figure 9b) would feel a repulsion charge from the mucin, due to the negative-negative charge interaction. Previous studies have shown the development of mucoadhesive film on surfaces which have more hydrophobic properties [35]. The NRL material shows more hydrophobic tendencies as less mucin was deposited onto the surface. Furthermore, mucin has been shown to have good wettability with different surfaces of different charges (such as denture fixations [36, 37]). The surface wettability also has an effect on the behaviour of the mucin [27]. Thus, it is hypothesised that there is more affinity of mucin for the XNBR material, which is aiding friction, allowing pins to be picked up easier in the Purdue Pegboard test. When applied to NRL, the mucin would be having less affinity for the surface and may be acting as a lubricant in the first instance, making the surfaces more slippery and harder to grip. However, over time, the movement and change in force when grabbing pins would aid thinning of the mucin viscosity and added to the film formation. Muco-adhesive films form over time and are not instantaneous, as these tests were 30 seconds/1 minute, there may have not been enough time to allow development of this film [12, 27].

This hypothesis is also supported by the results of the CSPDT which shows that mucin improved dexterity of both glove materials. The static positioning of the finger and thumb used to hold the tweezers may have allowed the formation of a thin muco-adhesive film, negating any microslips between the materials and the metal, improving frictional properties and performance [27]. Thus, XNBR + mucin performed quicker, presumably because the surfaces were closer together to begin with, as mucin interacted to pull them closer, and developed a film over time. Whereas the NRL will have taken slightly longer to produce a film the metal and the glove contact would be separated in the first instance. In conjunction with this, the tweezers had textured grooves on the surface to enhance grip. The mucin could have flowed into these and increased the contact area with the glove materials also, increasing friction through increased contact area. As the hand is always moving in the Purdue tests it is possible this tribo-film effect did not last as long, due to the film not having enough time to develop. This hypothesis could also support the increase in detection rate in the bumps test. There was an increase in detection rate with XNBR by 4% and a decrease with NRL by 4% when mucin was added. It is postulated that a film development would induce a ‘stick’ onto the bumps as the mucin is passed over, aiding further identification. On the other hand, if the mucin is acting as a lubricant, the solution would flood around the bump and carry the material over, decreasing the chance of identification. Although participants were instructed to press onto the surface only lightly, differences in measured effects could have occurred as a result of the varied forces applied. An alternative explanation is that the adhesive properties of mucin are exhibited more in XNBR due to the differences in patterns on the glove material surface. NBR had manufactured roughness at the tip of the finger, whereas NRL had a visible pattern around the material. The difference in surface irregularity may have trapped the mucin and provided more adherence sites and a larger contact area. The roughness profiles obtained of both of these glove materials at the finger however, showed similar surface roughness between the materials.

5. Conclusions

- Mucin is shown to affect the dexterity and sensitivity of medical glove users, producing different results through different interactions of the mucin with the different materials.
- Mucin has a greater affinity for the NBR material due to the polarity, leading to mucin-NBR interaction. On the other hand, the NRL material will repel the mucin through hydrophobic mechanisms and exhibit less interaction.
- In the XNBR gloves, the interaction greater gross dexterity and sensitivity was observed when mucin was added, whereas gross dexterity and sensitivity decreased in the NRL.
- In the fine dexterity, the addition of mucin increased dexterity. This is due to the formation of thin muco-adhesive films which will cause adhesion, circumventing micro slipping, aiding friction between the materials and the metal.
- This study has shown that medical glove assessments require closer attention to be focused on friction and performance, and how friction in modified when in contact with real-world contaminants.
- Further studies need to be conducted on the frictional properties of mucin with these glove materials to fully understand the mechanisms by which frictional differences are affecting the performance properties. This would better inform both glove manufacturers and glove users on the glove selection process. If bodily fluids are affecting the frictional interactions with materials, this could, potentially, be detrimental to performance.

6. References

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