THE EFFECTS OF GLOVE FIT ON TASK PERFORMANCE AND ON THE HUMAN OPERATOR

BY

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THESIS

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ABSTRACT

The hand is one of the most complex of all of the anatomical structures in the human body. It has been found that hand injuries are among the most frequent injuries that occur to the body, predominantly during industrial activities. It has therefore been concluded that more research is needed into protective factors, such as glove use. The design features of a glove emphasise either protection or performance. There is often a trade-off between increased safety and performance capability when donning gloves. It has been determined that gloves which are fitted and comfortable for the worker may provide the best compromise between protective functions and decreased performance.

This investigation aimed to assess the influence of glove fit on the performance attributes of industrial tasks, as well as on the responses of the human operator. Glove fit was analysed as 35 male participants donned three different glove sizes during each test, including a best-fitting glove, a glove one size smaller than best-fitting, and a glove one size larger than best-fitting. For each glove size, gloves of two differing materials were tested, namely nitrile and neoprene. A barehanded condition was also tested, totalling seven gloved/barehanded conditions for each test.

The seven conditions were assessed in a laboratory setting in a battery of tests. This consisted of components of task performance, including maximum pulling and pushing force, maximum torque, precision of force, tactility, speed and accuracy and dexterity. The performance responses were recorded, as well as participants' perceptual responses using the Rating of Perceived Exertion scale, and muscle activity. Six muscles were selected: Flexor Digitorum Superficialis, Flexor Pollicus Longus, Extensor Carpi Ulnaris, Extensor Carpi Radialis, Flexor Carpi Ulnaris and Flexor Carpi Radialis.

The results revealed that glove fit does affect certain aspects of performance, and influences human operator responses for selected task components. Furthermore, discrepancies were distinguished between working barehanded

and working with an optimally fitted glove. There was also a glove material effect established. Overall, it was found that muscle activity when exerting maximum force in a pushing and pulling direction was optimal with the nitrile glove material. Maximum torque performance was enhanced with the use of a best-fitting glove, as compared with an ill-fitting glove or barehanded work. Force precision was preferable when barehanded, as opposed to the tactility task which rendered optimal results with a best-fitting glove. The same was found for speed and accuracy results, as glove fit appeared to have no effect on performance, but performance was improved when participants were barehanded. Dexterity performance was the most conclusively influenced by the conditions, resulting in barehanded performance being optimal. However, should a glove be necessary for a given task, an optimally-fitted glove which is of a thinner material would be recommended.

It is necessary to distinguish the performance components of a task within industry and select the most appropriate glove for optimal performance and the least risk of overexertion.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Occupational injuries of the hand are common (Dias and Garcia-Elias, 2006), and are an economic burden for many industries (Skov *et al.*, 1999). Despite a large number of published materials regarding upper extremity disorders, the hand has not been thoroughly considered from an ergonomics standpoint (Kumar, 2004). Due to the hand's complex anatomical structure, and intense usage (Muralidhar *et al.*, 1999) ergonomic interventions are vital (Kumar, 2001).

The hand is the predominant medium for motor activity and the most important sensory and tactile organ (Napier, 1956), and therefore, perfect matching between hand devices, such as gloves, and hand characteristics is essential (Imrhan and Loo, 1989). There are good safety guidelines in most parts of the world and the use of correct safety gloves for certain tasks is recommended, although it may not be followed unanimously (Gaither, 1990). This is particularly notable in developing countries, as the laws designed to ensure the health and safety of people at work do not appear to have much impact (Asogwa, 1987).

The South African context

There is a growing concern for improving the working conditions of workers in industrially developing countries (IDCs), such as South Africa (Okunribido, 2000). Ergonomics has been found to be an essential component of any nation's development strategy (Okunribido, 2000), and it has been proposed that appropriate ergonomics in the design of equipment and the development of work practices can address the increasing performance and safety concerns. In order to design a product for human use, engineers have to rely on anthropometric data, otherwise the resulting product may turn out to be ergonomically incompatible (Lewin, 1969).

Research in industrialized countries has identified such incompatibility as being responsible for low worker productivity, reduced product safety and increased occupational hazards (Graves, 1992; Lewis and Narayan, 1993). In particular, there is scarce data available in IDCs on individual body parts, such as the hands (Sang-do, 1978; Gupta *et al.*, 1983; Mebarki and Davies, 1990), and it is evident that mismatch or incompatibility can exist between the hands of workers and the characteristics of the available equipment (Okunribido, 2000). Therefore, in order to improve hand performance or to prevent the negative influence of detrimental factors, ergonomics evaluations on manual performance have been found to be increasingly necessary (Hu *et al.*, 2008).

Hand injuries and hand protection

Each year, more than 1 million US workers receive emergency room treatment for acute hand injuries (McPherson, 2007). If that were not enough to demonstrate the need for improving hand protection in the workplace, 70% of workers who experienced hand injuries were not wearing gloves, and the remaining 30% of injured workers did wear gloves but experienced injuries because the gloves were inadequate, damaged or wrong for the type of hazard present (McPherson, 2007). The use of protective gloves with the right level of protection against mechanical risks is at the centre of employers' and occupational safety agencies' preoccupation (Harrabi *et al.*, 2006).

The use of protective gloves is recommended in a variety of working environments to protect workers from hazards and potential injuries (Berger *et al*., 2008), and they are frequently used in various manual operations (Shih and Wang, 1997). Legislation exists (OSHA's Hand Protection Standard 29 CFR 1910.138, 2004) which mandates that employers select appropriate hand protection and impel employees to use the hand protection, being exposed to potential environmental hazards (McPherson, 2007). However, legislation in IDCs, where it exists, is ineffective (Okunribido, 2000), and, furthermore, workers often prefer to work bare-handed (Berger *et al.*, 2008). This is due to the fact that although the safety function of gloves has never been questioned (Shih and Wang, 1997), glove use can have unwanted side effects (Kovacs *et al.*, 2002). There are conflicting findings regarding the effect of gloves on workers and performance (Shih and Wang, 1997), with the predominant opinion being that wearing gloves hinders performance (Berger *et al.*, 2008).

The selection of protective gloves is often a compromise between the optimal level of protection desired and the comfort and degree of dexterity that is required for performing the tasks (Harrabi *et al.*, 2006). A protective glove which is designed to give the best level of resistance against all potential risks may not be useful if it prevents the worker from performing tasks adequately, or creates a high level of muscular fatigue, both of which may lead to a likelihood of ill-compliance to wear the safety glove (Harrabi *et al.*, 2006). Due to the fact that gloves have to be worn for a considerable fraction of working hours, the comfort and ergonomical aspects of this protective clothing are of importance (Havenith and Vrijkotte, 1994).

In order to get workers actually to wear gloves, employers must first be able to choose the right glove to suit the workers' needs. It is therefore important to note who will be wearing the gloves, the type of equipment that will be used, the specific work that person will perform, and the estimated level of dexterity required in order to perform the job safely (McPherson, 2007). Due to the diverse assortment of potential occupational hand injuries, the selection of the most appropriate protective hand wear is challenging (McPherson, 2007). Discomfort or ergonomical properties can strongly reduce the motivation of workers to wear the necessary protective equipment (Havenith and Vrijkotte, 1994). Finding ways to assist workers' compliance with glove wearing protocols will considerably improve the work environment (McPherson, 2007).

A Kimberley-Clark Professional survey of safety personnel at the 2006 National Safety Council Congress found that 57% of respondents who observed personal protective equipment non-compliance in the workplace attributed it to poor fit or discomfort (McPherson, 2007). Fortunately, because glove material characteristics today have become so advanced, the development of new glove technologies tends to focus not just on function but also on issues of fit and comfort. If a glove is more comfortable to wear, users are more likely to comply with personal protective equipment protocols, which is mutually beneficial to workers and employees. Proper fit is therefore critical as it leads to improved compliance and ultimately productivity (McPherson, 2007).

The need to address fit

It has been ascertained that gloves should fit properly in order to assure an increased level of performance from workers, depending on the task (Sweeney, 2008). Certain task performance decrements can be attributed partially or wholly to poor fit, as well as the thickness and flexibility of the material (Bellingar and Slocum, 1993). However, a recent literature search revealed few studies that have investigated the effect of glove fit on performance (Tremblay-Lutter and Weihrer, 1995). It has consequently been established that there is a need to consider the fit afforded by a glove in order for it to provide optimal function (Tremblay-Lutter and Weihrer, 1995). The evaluation of the effect of this singular glove characteristic is therefore necessary (Chang and Shih, 2006).

STATEMENT OF THE PROBLEM

Despite previous research, and the clear need to focus on the hand/glove interface and whether this is a significant contributor to inefficiency, or injury within industry, this problem continues to plague the working population. The objective of this research was to identify whether significant interaction effects exist between poor glove fit; and decreased task performance and diminished human work capacity.

Glove material characteristics, specifically glove fit, affect the worker, and therefore the ability of the worker adequately to perform a manual task. There are a number of concerns regarding glove use, as the extent of fit between the hand and glove has been found to have a significant influence on the performance compromises with gloves. A need has been identified for the evaluation of the effect of this glove characteristic.

RESEARCH HYPOTHESIS

The study aimed to identify whether an interaction between glove fit and worker performance exists, and whether any exaggerated effects, such as increased muscle activity and perceived exertion would be observed due to this interaction. It was expected that components of performance and worker effort would be affected, as the fit of the glove varied.

It was proposed that different sized gloves (glove fit) would elicit different responses. Responses included:

- Performance parameters
  - maximum force in a pushing and pulling direction,
  - maximum torque,
  - precision of force in a pushing and pulling direction,
  - dexterity,
  - tactility,
  - and speed and accuracy;

and

- human capabilities
  - muscular activity

- and perceptual responses.

Different sized gloves included an optimally fitting glove, which was determined using subjective observation, and anthropometric measurements; a glove which was a size smaller than the optimally sized glove; and a glove which was a size larger than the optimally sized glove.

STATISTICAL HYPOTHESES

The following hypotheses outline the expectations that an optimally fitted glove would render different responses to being barehanded; and that the glove with the best fit would elicit different responses than gloves that are ill fitting. The responses would include both performance parameters and human capabilities.

Performance responses

The null hypothesis states that the performance responses would be the same between the bare-handed condition and the best-fitting glove condition; and between the smaller-than-best-fitting (optimal) glove condition, the best-fitting glove condition and the larger-than-best-fitting glove condition.

H_o: $\mu_{\text{bare-handed responses}} = \mu_{\text{optimal glove responses}}$

$\mu_{\text{small glove responses}} = \mu_{\text{optimal glove responses}} = \mu_{\text{large glove responses}}$

The alternative hypothesis proposes that the performance responses would be different between the bare-handed condition and the best-fitting glove condition; and between the smaller-than-best-fitting (optimal) glove condition, the best-fitting glove condition and the larger-than-best-fitting glove condition.

H_a: $\mu_{\text{bare-handed responses}} = \mu_{\text{optimal glove responses}}$

$\mu_{\text{small glove responses}} = \mu_{\text{optimal glove responses}} = \mu_{\text{large glove responses}}$

Where: responses = components of performance: maximum pushing and pulling force; peak torque, total work, average power; precision of force in a pushing and pulling direction; dexterity; grasp force as a measure of tactility; movement time and deviation from target as a measure of speed and accuracy.

Human responses

The null hypothesis states that the participants' feedback would be the same between the bare-handed condition and the best-fitting glove condition; and between the smaller-than-best-fitting (optimal) glove condition, the best-fitting glove condition and the larger-than-best-fitting glove condition.

H_a: $\mu_{\text{bare-handed responses}} = \mu_{\text{optimal glove responses}}$

$\mu_{\text{small glove responses}} = \mu_{\text{optimal glove responses}} = \mu_{\text{large glove responses}}$

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H_a: $\mu_{\text{bare-handed responses}} = \mu_{\text{optimal glove responses}}$

$\mu_{\text{small glove responses}} = \mu_{\text{optimal glove responses}} = \mu_{\text{large glove responses}}$

Where: responses = muscle activity of six muscles, namely the Flexor Digitorum Superficialis, Flexor Pollicus Longus, Extensor Carpi Ulnaris, Extensor Carpi Radialis, Flexor Carpi Ulnaris, Flexor Carpi Radialis; and perceptual responses (ratings of perceived exertion).

DELIMITATIONS

The study used a sample of 35 healthy, male participants, all free of musculoskeletal injury. All of the participants had a glove size of 8, or 9; and none were accustomed to working with gloves.

Participants were given standardised instructions for the protocol. During the protocol, each participant performed a battery of tests. Each test within this battery assessed a component of task performance, including a test of maximum pushing and pulling force, maximum torque, precision of force (pushing and pulling), tactility, dexterity and speed and accuracy. The tests were executed by each participant seven times: once barehanded, and six times with gloves of varying size and material (two materials * three different sizes). The sizes included a best-fitting glove size, and a glove size smaller than best fit, and a glove size larger than best fit.

Data was collected on each participant using a DataLogger, and electrodes on six relevant muscles. This provided information on participants' muscle activity during the test battery. Perceptual responses of the participants were recorded using the Rating of Perceived Exertion scale, presented at the conclusion of each test.

LIMITATIONS

The following factors presented limitations to the study, and should therefore be considered when examining the results.

Participants were not randomly selected, but were student volunteers from different departments at Rhodes University. This is not representative of the user population, and may limit the applicability of the results.

Although participants were familiarised prior to testing in each of the conditions, the environment in which they were tested was not familiar to them.

Furthermore, the equipment used required electrodes to be placed on the skin throughout the testing. These factors augmented the lack of familiarity and may have influenced the participants' responses.

Clear and detailed instructions on the use of the rating scales for perceptual responses were given to each participant; however, the researcher had no means of ensuring that the participants had a clear understanding and could use the scale properly. Since this scale is a 'self-report' chart, the validity needs to be assessed in this light.

Although best-fitting glove size was allocated to each participant using both objective measurements, and subjective verification, each participant's best-fitting glove may not have been the perfect fit. This was due to the fact that hands come in limitless dimensions, and although the glove may be the best fit, with regards to hand width, the length of the glove may be greater than the optimal length for the given hand, or vice versa. Gloves were not individualised for each participant. These discrepancies in the hand/glove interface may have affected performance parameters differently. Therefore, when considering 'best fit', take into account that this is the best fit as compared to the other available glove sizes, and not necessarily the 'perfect fit'.

It needs to be considered that the surface area on which the electrodes were attached was small, and hand and arm muscles were difficult to isolate. Therefore, although the process of placing the electrodes on each of the relevant muscles was done with care, the electrodes were participant to cross-talk from nearby muscle activity. The influence varied, depending on the muscle studied but, should have been similar across all participants as standardised electrode settings were used.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

A study conducted by the Liberty Mutual Research Institute for Safety found that glove use significantly reduces occupational hand injury by 60% (Wagner and Barker, 2006). This finding is further confirmed by Hertz and Emmett (1986) and Sorock *et al.* (2004) in two controlled studies. It has been determined that the use of gloves can contribute to, or degrade performance (Fleming *et al.*, 1997), and although gloves are a necessity in many workplaces, there are inherent disadvantages (Muralidhar *et al.*, 1999).

Bishu and Kim (1995) hypothesise that performance capabilities are compromised considerably when gloves are donned, as gloves influence task time (Muralidhar and Bishu, 1994), dexterity (Bradley, 1969b; McGinnis *et al.*, 1973), grip strength (Hertzberg, 1955; Cochran *et al.*, 1986), and range of motion (Griffin, 1944). While the safety function of gloves has never been in any doubt, understanding the effect of gloves on task performance is conflicting (Bishu and Kim, 1995), as less information has been presented regarding the influence of gloves on the quality and efficiency of work performance (Kovacs *et al.*, 2002).

Performance levels on manual tests have been found to decline as thickness of the hand covering is increased (Bensel, 1993). This suggests that from the perspective of worker productivity in a hazardous environment, thickness is important in selecting protective hand wear. However, the thickness of the hand wear to be used is determined primarily on the material characteristics which are required for isolation from the environmental hazards (Shwope and Hoyle, 1985). When selecting the appropriate gloves for a task in a particular working environment, there is a need to ensure that the protective integrity of the hand wear is not compromised by the items that the workers must handle

(Bensel, 1993). This consideration dictates the material and minimum thickness of protective gloves for a given situation, and takes precedence over the efficiency of the manual manipulations (Bensel, 1993). Therefore, despite potential glove design interventions, to promote human performance, regarding glove thickness and material, the application within industry is limited. A glove characteristic which is modifiable and which can be practically implemented is glove fit.

In terms of glove function, glove fit has been found to have the highest priority (Scanlan *et al.*, 2004). However, there are infinite variations in hand size and a need for standardization in glove manufacturing in order to keep glove cost reasonable. The topic of glove-hand fit is therefore complex (Muralidhar *et al.*, 1999). A recent literature search revealed very few studies that have investigated the effect of glove fit on performance (Bradley, 1969a; Bradley, 1969b). Therefore, a void remains in the literature regarding the direct effects of glove size on performance and productivity (Tremblay-Lutter and Weihrer, 1995).

HAND PROTECTION

Hand injuries

The hand is the most complex of all anatomical structures in the human body, and possibly the part which is most frequently used (Muralidhar *et al.*, 1999). It is a very valuable, multipurpose tool in all environments (Bishu and Kim, 1995). The human hand offers probably the most effective means of accomplishing intricate manual work, due to the fact that it can perform specialized tasks which require dexterity, manipulability and tactile perception (Bishu *et al.*, 1994). The incidence rate of hand injuries studied in seven manufacturing environments around the world ranged from 4 to 11 per hundred workers, yearly (Sorock *et al.*, 2001). Hand injuries constitute 6.6% of all injuries and 28% of injuries to the musculoskeletal system (Packer and Shaheen, 1993), and have been found to be second only to back strain and sprain in the number of days away from work cases (Courtney and Webster, 1999). They predominantly occur during industrial activities (Johns, 1981; O'Sullivan and Colville, 1993), and young manual workers are the demographic which is most exposed to hand injury (Johns, 1981; Oleske and Hahn, 1992; O'Sullivan and Colville, 1993; Trybus *et al.*, 2006).

Approximately 1 million workers in the United States of America receive emergency medical treatment for acute hand injuries, yearly, which range from cuts, blisters, abrasions, lacerations, burns, punctures and fractures (Wagner and Barker, 2006). Therefore, in addition to physical pain, hand injuries take a financial toll, as the cost per injured worker averages $17000 which includes medical costs, lost time (approximately 5 days), downtime, clean up, and indemnity costs (Sweeney, 2008). Occupational hand injuries are an economic burden for any community (Skov *et al.*, 1999), and the overall drain on employee productivity is evident.

Few developing countries can provide accurate statistics on the nature and frequency of occupational injuries however, evidence exists to show that occupational injuries are a significant and growing problem in developing countries, such as South Africa (Asogwa, 1987). In addition to this, there is negligence with regards to factory regulations ensuring safety, in developing countries (Al Zahrani *et al.*, 1997). As a result, it is likely that the incidence of industrial hand injuries is higher in developing countries (Mathur and Sharma, 1988), and it is therefore very important to protect the hands from various environmental risks.

Despite the high frequency and significant amount of lost work time due to hand injuries, these injuries are poorly understood, and it has been found that more research is needed into potentially modifiable risk, or protective factors, such as glove use (Sorock *et al.*, 2001).

Safety gloves

Hand injury prevention ultimately depends on a combination of factors, including engineering and administrative controls, situation awareness and very importantly, the use of hand gloves (Laing *et al.*, 1997). A secondary hand surface, such as gloves can provide the required protection from potential hand injury (Muralidhar *et al.*, 1999). Almost all industrial tasks necessitate the use of gloves to protect the hand from the environment, whether this environment consists of sharp tools, extreme temperatures or harsh chemicals (Bishu and Kim, 1995). Protective gloves are as varied as the jobs in which they are used (Willms, 2006). Specific tasks in which glove use should be increased are manual materials' handling tasks (Sorock *et al.*, 2004a).

According to the Department of Labour's Occupational Safety and Health Administration (OSHA) (2009), personal protective equipment, specifically hand protection should be adhered to, in concurrence with specific legislation. OSHA is unaware of any gloves that provide protection against all potential hand hazards, and commonly available glove materials provide only limited protection. Therefore, it is important to select the most appropriate glove for a particular application (OSHA, 2009). It is also essential to know the performance characteristics of gloves relative to the specific hazard anticipated. Before purchasing gloves, the employer should request documentation from the manufacturer that the gloves meet the appropriate test standards for the hazard anticipated (OSHA, 2009). Other factors to be considered for glove selection in general include: the work activities of the employee, which should be studied in order to determine the degree of dexterity required, the duration, frequency and degree of exposure to the hazard, and the physical stresses that will be applied (OSHA, 2009).

Industry standards require that manufacturers test gloves' physical dimensions, which include width, length and thickness; and the gloves' strength, and ability to withstand pressure, or to pass the leak test (Korniewicz *et al.*, 1991). These standards have been established by the American

Society for Testing and Materials, and are regulated by the United States Food and Drug Administration. Current quality control mechanisms are in place to ensure that both domestic and foreign manufacturers meet these minimum standards for protective gloves (Korniewicz *et al.*, 1991). However, although these protective requirements are retained, gloves' physical dimensions, and consequent fit are often overlooked.

Compliance with safety guidelines

There are sound safety guidelines in most parts of the world, including the majority of developing countries. The use of correct safety gloves for certain tasks is recommended, although it may not be followed universally (Gaither, 1990), specifically in developing countries, where unfortunately, health and safety laws do not appear to have much impact (Asogwa, 1987).

A study has shown that participants are more likely to wear gloves if the participant received relevant safety training on the task and if the company size is small (less than 50 employees) (Sorock *et al.*, 2004). However, the cause of hand injury is frequently lack of compliance with the standard principles of work safety (Trybus *et al.*, 2006). In two large studies of acute hand injury at work, 72% and 81% of injured workers reported not wearing gloves at the time of injury (Sorock *et al.*, 2004a). As seen in the construction industry, and in the industrial segment, 58% of workers perform tasks barehanded, and among the 42% who do wear gloves or have gloves provided, more than half remove their gloves at some point during the work shift so they can complete certain tasks. Therefore, more than 79% of workers in the construction industry do not wear gloves some time during the day (Sweeney, 2008). In a study conducted by Al Zahrani *et al.* (1997), 81% of workers investigated were not following safety measures at the time of injury, indicating a predisposing factor to industrial hand injuries (Al Zahrani *et al.*, 1997).

Despite recommendations, applicators do not wear gloves because they do not fit well, are uncomfortable, cause a loss of tactile sensation, decrease the ability to perform tasks and create a loss of dexterity and mobility (Sheridan, 1954; Saul and Jaffe, 1955; Thomas at al., 1976; Bensel et al., 1987; Tremblay, 1989). According to Sweeney (2008), reasons given for this lack of safety compliance are that workers cannot find the comfort, dexterity and protection required in a single hand protection product. Sorock *et al.* (2001) further broke down the rationale behind workers' resistance to comply with glove regulations. Responses to not wearing gloves included: not practical or hard to work with them on (57%), not required to wear them (39%), unsafe to wear gloves for the work being done (23%), did not think they were needed (18%) and not allowed to wear them (12%) (more than one response was permitted). It can be seen that the predominant motivation for not wearing gloves is that they are found to be impractical for the task at hand, or it is difficult to work with them on. It has been determined that glove use can be improved, and hand injuries can be reduced if hand implements are well-designed, with an emphasis on comfort (Lewis and Narayan, 1993) and safety training is instigated, including proper selection of appropriate gloves (Sorock *et al.*, 2004a).

Most importantly it has been found that gloves should fit properly in order to assure a high level of performance, and productivity (Wagner and Barker, 2006; Sweeney, 2008). Gloves that are snug fitting and comfortable for the worker may provide the best trade-off between protective functions and decreased performance (Sorock *et al.*, 2004b), therefore ensuring higher compliance with glove use and legislated safety guidelines, regarding gloves.

GLOVE FIT

The need to address glove fit

The fit of protective clothing directly affects both workers' performance and the extent of the protection, which is provided, and is therefore of paramount concern (Robinette, 1986). In order to improve hand performance and to prevent the negative influence of detrimental factors, such as glove use, ergonomics evaluations on manual performance are necessary (Hu et al., 2008). According to Lewin (1974), the basic requirements for protective hand wear include a very good fit, with the thumb directed towards the centre of the assembled fingers; a knuckle component, which can expand crosswise; and a palmer side of the glove, which is shorter than the dorsal side, in order to avoid folds forming in the palm. Furthermore, fit issues incorporate finger length, which must not be so long that the glove can get caught in moving equipment; and overall sizing, which ensures that the hand circumference is not so small that workers' range of motion is impaired (Wagner and Barker, 2006). If a hand protection product is too large, it will slide around on the worker's hand and result in inadequate protection. However, it has also been hypothesized that gloves which are too snug may decrease dexterity and be uncomfortable, the consequence of which is workers removing the glove (Sweeney, 2008). A fit test should be performed at various critical stages of glove design and sizing. However, a fit test is often executed after problems have been identified in the fit or function of the manufactured item (McConville, 1986).

A study undertaken by Creely and Cherrie (2001) established that the most effective performance results occur with optimal glove fit. According to Muralidhar *et al.* (1999), the extent of fit between the hand and glove has a significant influence on the performance compromises with gloves. A need has therefore been identified for the evaluation of the effect of this singular glove characteristic (Chang and Shih, 2006). Wagner and Barker (2006) further emphasized the reality that the more comfortable a glove is to wear, the more likely it is that workers will comply with wearing protocols. It is important to acknowledge that proper protection does not have to result in worker discomfort (Wagner and Barker, 2006).

Anthropometric problems

Protective equipment needs to be compatible with the physical characteristics of the workers due to the fact that mismatches between human anthropometric dimensions and equipment dimensions contribute to discomfort, accidents, biomechanical stresses, fatigue, injuries and consequently decreased productivity (Mandahawi *et al.*, 2008). It is not possible to address problems with fit without accurate body measurements (Istook and Hwang, 2001). Researchers have acknowledged the importance of using relevant anthropometric data in equipment design (Meagher, 1986, 1987; Rosenblad-Wallin, 1987; Abeysekera and Shahnavaz, 1989; Graves, 1992; Imrhan *et al*., 1993; Lewis and Narayan, 1993; Loslever and Ranaivosoa, 1993; Okunribido, 2000; Kar *et al.*, 2003). It is necessary to have reliable anthropometric data in order for products to be suitable for the intended users (Ashby, 1978). Sizing problems for protective clothing and equipment are more significant than for traditional clothing, as many protective items do not have the sizing history, which traditional clothing has. Each item of personal-protective equipment is designed to meet a specific need, and must fit and function within specific limits in order to be considered successful (McConville, 1986).

Problems with fit are often derived from outdated and inaccurate measurement data (Strydom and de Klerk, 2006). Anthropometric data for industrially developing countries is lacking (Mandahawi *et al.*, 2008), and it is assumed that the anthropometric standards used by the South African industry are outdated. It is therefore important to obtain current measurements of this population (Strydom and de Klerk, 2006). A major challenge for manufacturers of protective clothing is the establishment of a sizing system which accommodates the body size variation of the user population, while providing a good fit for individual users (McConville, 1986). Designers often work on the assumption that one size fits all (Buchholz, 1992), however, research has shown that there are anthropometric differences between different populations in almost every part of the human body

(Abeysekera and Shahnavaz, 1989). According to Sperling and Avén (1985) adult hands vary significantly in size and proportion and significant differences in hand dimensions exist between groups within a nation (Mandahawi *et al.*, 2008). This is a considerable problem within South Africa, due to its multi-cultural population (Ashby, 1978). Dimensions of the hand are important, and there is therefore a need to introduce changes in equipment design, especially for specific body parts, such as the hands (Abeysekera and Shahnavaz, 1989). Hand measurements, as proposed by Rosenblad-Wallin (1987) include hand circumference and length, which were first chosen as the critical measures for closer studies (Coletta *et al.*, 1976). The length measurements are predominantly skeleton measurements, and the circumference measurements are affected by the muscular volume (Sperling *et al.*, 1983). The length measurements were found to be strongly correlated to each other, as were the circumference measurements to the width measurements. The fundamental hand dimensions were therefore the dorsal hand length and hand circumference (Rosenblad-Wallin, 1987). It should be noted that differences in overall hand dimensions, including hand length, maximum breadth, and breadth at the knuckles, do not necessarily correspond to the differences in finger segments. The same lack of correspondence also holds for depths (Mandahawi *et al.*, 2008). The significance of this finding is that design parameters for gloves, which use extrapolated data from overall hand length and breadth, instead of finger segment measurements, may produce problems in fit (Mandahawi *et al.*, 2008).

The conversion of hand measures into glove measures is indeterminate as there are no fitting tolerances available between the two measures (Sperling and Avén, 1985). An investigation done by Tremblay-Lutter and Weihrer (1995) demonstrated that anthropometric data should not be directly translated into glove design dimensions. The sizing of working gloves is currently based predominantly on experience, as opposed to scientific studies (Coletta *et al.*, 1976; Sperling and Avén, 1985).

THE EFFECTS OF GLOVE USE

It has been indicated that protective hand wear impairs manual performance (Bensel, 1993; Muralidhar *et al.*, 1999), and that bare-hand performance is superior to glove-hand performance (Plummer *et al.*, 1985; Robinette *et al.*, 1986). According to Bishu and Kim (1995) glove use results in an increase in grip span and an earlier pressing of fingers with each other. The former should increase grip strength, and the latter should reduce the strength. It appears that the effect of increase in grip span with gloves is counteracted by the reduction in the inter-digital movements and range of motion when gloves are worn. This results in a net reduction in performance (Bishu and Kim, 1995). It has been determined that degradation in motor performance is less than that of sensory performance due to glove use (Chang and Shih, 2006). Amongst the various hand performance factors, Muralidhar *et al.* (1999) identified dexterity, grip strength and range of motion as being affected by glove use. A proposed reason for this is that gloves can reduce sensory input, and change hand dimensions (Mital *et al.*, 1994), as hand thickness with glove use may increase from 8mm to 40mm (Damon *et al.*, 1966).

The effects of wearing gloves on work performance are easily discernable. Gloves may inhibit hand movement, causing problems with both precision and speed, and ultimately causing problems with the work task, and with production (Kovacs *et al.*, 2002). The effects of gloves on the individual worker however are more challenging to identify.

Human operator effects

Perceptual responses

Glove condition and the muscle action during a handgrip have a distinct influence on perception (Fleming *et al.*, 1997). It has been concluded that perceived exertion is the single best indicator of the degree of physical pain being experienced (Borg, 1982). If the level of fatigue experienced by a worker is not adequately realized, serious hazards in industry could occur.

Spielholz *et al.* (2001) concluded, however, that subjective self reports are an imprecise exposure assessment method, and should not be used exclusively for any scientific assessment of exposure to physical risk factors, such as hand force.

Muscle activity and electromyography (EMG)

Direct measurement methods, such as EMG, are often used to measure required forces or muscle activities to complete tasks. This provides detailed information that is more precise than other exposure assessment methods (Koppelaar and Wells, 2005). EMG measures muscle function through the assessment of muscle activity. When muscle fibres contract, small electrical changes occur within the muscle. EMG analyses these electrical impulses occurring during muscle contraction (Laursen *et al.*, 1998). Surface EMG is common in ergonomic evaluations due to the fact that it is non-invasive and allows for convenient measurement during a range of activities. However, this technique is susceptible to cross-talk from adjacent muscles (Laursen *et al.*, 1998).

For inter and intra individual muscular comparisons to be made, maximum voluntary contractions (MVCs) are performed. MVCs are the maximum value that a participant can voluntarily generate during an isometric contraction (Kumar, 2004).

EMG evaluation of hand gripping tasks has focused on flexor forearm muscles, as the basic function of gripping is finger flexion activated by the finger flexors in the forearm. However, in order to maintain a straight wrist, the wrist extensors need to be activated to counteract the wrist flexion torque, caused by the finger flexion tendons (Hägg and Milerad, 1997). Consequently, gripping activity involves both flexion and extension muscles in the forearm.

The Flexor Digitorum Superficialis (FDS) is the prime mover, finger flexor, and consequent grip forming muscle. The fourth digit, which is served by the Flexor Digitorum Superficialis, contributes 25% of total grip force, regardless of the wrist position (Blackwell *et al.*, 1999). Despite this, it has been found that the extensor muscles of the forearm are utilised to a greater degree than the Flexor Digitorum Superficialis.

Furthermore, Flexor Digitorum Superficialis activation has been found to increase as a result of additional finger load caused by glove stiffness (Hägg and Milerad, 1997). Larivière *et al.* (2004) demonstrated that wrist extensor muscles were more sensitive than flexors to glove conditions.

It has been suggested that larger, less flexible gloves inhibit the ability to produce force outputs, as compared with barehanded and more flexible glove conditions. Kovacs *et al.* (2002) discovered that glove fit may have a significant effect on the transfer of flexor muscle activity to force, when a larger-than-best-fitting glove is donned. The larger glove size may increase the grip diameter used during the exertion or allow slight wrist extension, resulting in a change of the length-strength relationship of the flexor and extensor muscles. Larger gloves create slipping between the glove-handle interface creating a slight extension of the wrist resulting in the grip occurring at a less optimal muscle length (Kovacs *et al.*, 2002).

It has been therefore been determined that gloves may alter the recruitment and force of the forearm muscles. Consequently, the long-term use of these muscles, coupled with increased force requirements during a given task may lead to cumulative trauma (Kovacs *et al.*, 2002). According to Chang and Shih (2006) wearing gloves results in greater ratings on fatigue and lowered recovery rates. The increase in hand fatigue when gloves are worn could be due to the fact that a certain amount of energy is required to manipulate the glove (Fleming *et al.*, 1997). It has been concluded that a certain amount of muscle force is lost in the hand-glove interface (Sudhakar *et al.*, 1988). It has been hypothesised that this reduction in grip strength accelerates grip fatigue, therefore contributing to musculoskeletal disorder (MSD) risk.

Fatigue plays a significant role in limiting hand performance (Fleming *et al.*, 1997) and may lead to difficulty in holding and controlling tools during work tasks, resulting in accidents and injuries (Fleming *et al.*, 1997). Although there has been extensive research undertaken to assess hand grip, the factors which may contribute to hand grip fatigue have been neglected (Fleming *et al.*, 1997). Gloves can be used within the working environment to aid grip; however, the effect of glove use on grip performance has been investigated, with conflicting results. The use of gloves, regarding handgrip fatigue, is that hold time decreases and fatigue accelerates accordingly (Fleming *et al.*, 1997). However, Mital *et al.* (1994) demonstrated a positive influence of gloves, as the applied torque of workers increased with the use of gloves, without any change in muscle activity. It was consequently considered that quicker fatigue due to loss of muscle activity would not occur in the gloved condition. In a study by Bishu and Kim (1995), when comparing gloved and barehanded performance, similar electromyographic activities of the lower arm muscles were found. However, the gloved hand condition resulted in reduced strength capacity.

Performance effects

Force

It has been stated by Kovacs *et al.* (2002) that a link between gloves and the risk of injury may be determined through the evaluation of the effects of gloves on the exertion of force. Gloves may reduce the level of force which can be exerted on an object (Sudhakar *et al.*, 1988). Consequently, an elevated internal force must be accomplished in order to reach the force output required for the task. This can result in an increased risk of the worker to incur both acute and cumulative injuries (Kovacs *et al.*, 2002). Acute injuries may occur when fatigue of the primary muscles leads to recruitment of secondary, smaller muscles. These muscles are characteristically used for motion control, as opposed to strength, and may therefore not be capable of providing adequate strength. This results in problems with both material handling and tool control (Kovacs *et al.*, 2002).

Most working tasks require a certain degree of hand force application. There is a complex relationship between industrial design, and applied force, as poor ergonomic design has been found to determine a decrease in hand force (Kumar, 2004).

Hand force has been acknowledged as a mechanical risk factor for the development of musculoskeletal disorders (Koppelaar and Wells, 2005). ‘Hand force’ is infrequently well-defined, and is commonly described by four approaches: describing the contact force between the object and the hand; describing the weight of the object; obtaining a rating of effort; and lastly, using EMG to estimate muscle loading (Koppelaar and Wells, 2005). Within this investigation, the pushing/pulling/torque handgrip, the rating of perceived exertion reports, and the EMG measurements of forearm muscles have characterised the hand force exerted by participants.

Gloves and hand tools accomplish the task of transmitting muscle force onto a workpiece. It has been established that the capability of hands to exert force or torque is severely influenced by the use of gloves (Mital *et al.*, 1994). When wearing gloves, a fraction of the force generated by muscular contraction may be directed in maintaining the grip and therefore result in reduced force production (Mital *et al.*, 1994). Grip strength is widely used in many industrial tasks, and is produced by the thumb flexors exerting force in opposition to the total force produced by the other fingers’ flexors (Kumar, 2004). During grip exertion, the most exposed areas of the hand are the metacarpal regions (Muralidhar and Bishu, 2000). Reduction in grip force when using gloves has been reported by many researchers (Hertzberg, 1955; Lyman, 1957; Hertzberg, 1973; Swain *et al.*, 1970; Sperling, 1980; Cochran *et al*., 1986; Sudhakar *et al.*, 1988).

Bishu and Klute (1995) found that maximum exertion is unstable, and deviates as much as 30%. Maximal grip strength is dependent on postures, and gloves (Lyman and Groth, 1958; Cochran *et al.*, 1986; Bishu *et al.*, 1994; Bishu and Klute, 1995). According to Hertzberg (1955, 1973) grip strength declines 20% when gloves are donned. Reduction in grip strength may be up to 30% or more, as found by Lyman (1957) and Sperling (1980). Cochran *et al.* (1986) reported a reduction in grasp force due to gloves ranging from 7.3% to 16.8% when compared to no gloves. Sudhakar *et al.* (1988) found the peak grip strength with rubber and leather gloves to be 10-15% lower compared to grip strength without gloves, even when there was no significant difference in muscle activity between glove and no-glove conditions. Sudhakar *et al.* (1988) stated that thicker gloves impact the biomechanics of the hand, which causes an increase in the length and thickness of the digits, therefore resulting in the forearm flexors and extensors exerting more force.

Kovacs *et al.* (2002) observed significant differences between the peak forces of different glove types, and suggested that the characteristic aspects of different gloves, such as material and size can affect workers' maximum force production. Glove material may influence the force output due to the elasticity and flexibility of the material. Some reduction in force transmission may be due to stiffer, less elastic gloves. Gloves which fit the worker well can maximise the transfer of muscular force to grip force, reducing the amount of over gripping required to maintain the desired grip force (Kovacs *et al.*, 2002).

These investigations, which focus on the force exertion capability of workers with gloves, have been predominantly concerned with activities which require compressive forces. There are, however, many industrial activities which require a different kind of force exertion (Mital *et al.*, 1994), amongst them, one of which is torque.

Torque

Hand torque exertions are frequently required in various work situations, such as operating hand tools and valves (Mital *et al.*, 1994). Three types of torque exertions have been identified, including wrist pronation/supination, extension/flexion and radial/ulnar deviation (Shih and Wang, 1997). Kong and Lowe have established that activities of the flexor muscles are greater than that of the extensor muscles in horizontal handle orientation, such as that during the study's torque exertion test.

There are conflicting findings on the effects of gloves on torque performance (Shih and Wang, 1997). According to Mital *et al.* (1994) torque exertions have been found to increase with gloves, however the increase does not reflect a corresponding increase in muscle activation. Therefore there is no loss of muscular exertion at the glove-hand interface when using wrenches and screwdrivers, but there is an amplification of muscular activity that is transmitted onto the workpiece (Mital *et al.*, 1994). This contradicts the normal expectation that gloves would lead to quicker onset of fatigue, due to the loss of muscular activity, consequently leading to potential cumulative trauma disorders (Mital *et al.*, 1994).

Precision of force

Increased automation and new processes have resulted in a steady transformation of the nature of work in industry. The result is a high prevalence of light, manipulative tasks, including precision tasks, which are highly repetitive with a focus on the upper extremity (Sood *et al.*, 2007). Precision tasks are commonly considered to be light, manual tasks, and have therefore been perceived as less risk to the worker than heavy manual materials' handling tasks (Graf *et al.*, 1995).

The ability to generate a high force does not necessarily indicate a person's ability to maintain a percentage of that force over time (Nicolay and Walker, 2005).

Although sub-maximal forces that are held for a longer duration are required in the majority of working environments, more frequently than maximal forces, little research has focused on this topic (Lyman and Groth, 1958; Westling and Johansson, 1984; Radwin and Oh, 1992). It appears that glove effects are different under different levels of exertion (Bishu *et al.*, 1994) and it has been stated that sub maximal force tasks are preferable to assess gloves, as it allows for better application to more functional, everyday tasks (Larivière *et al.*, 2004). In order to optimise task performance and workers' safety, exertion levels must be considered when allocating gloves (Buhman *et al.*, 2000).

Tactility

Tactile sensitivity includes sensitivity to temperature, weight, texture, size, shape, and other attributes which can be sensed through touch. Tactile sensitivity is referred to as tactility, which is the ability to detect changes in any of the mentioned attributes (Buhman *et al.*, 2000). During the investigation, participants' tactility was measured through the assessment of a grasp force.

Participants adopted a pulp pinch, which, as classified by Sollerman and Sperling (1978), involves digit I and digit II. The use of pinch force is needed in the majority of industrial tasks, during which the most exposed hand regions are the dorsal surface of digits I, II and III (Muralidhar and Bishu, 2000). Small objects are handled between the tips of digit I and digit II, in a precision grip, which can be accurately controlled (Napier, 1956). Westling and Johansson (1984) have found that force control during gripping tasks is affected by factors of friction, weight and individual safety margin. The grip applied whilst holding an object stationary in space is critically balanced, such that accidental slipping between the skin and the object does not occur, and the grip force does not reach exceedingly high values (Westling and Johansson, 1984). A grip which is too firm may lead to muscle fatigue, damage to a fragile object, or cause injury to the hand (Westling and Johansson, 1984). It has been determined that three factors primarily influence the magnitude of the pinch force: the weight of the object grasped, the friction between the skin and the object, and the safety margin factor related to the individual (Westling and Johansson, 1984).

This motor response is achieved through a physiological mechanism, which provides the central nervous system with information related to the friction between the object, and the skin of the fingers. This sensory perception in the hand is dependent on mechanoreceptors, densely distributed over the palmer area, principally at the tips of the fingers. Therefore, feedback from the hand plays a critical role for a grasping task, and enables the hand to control the amount of force exerted (Westling and Johansson, 1984). The importance of the capacity to adjust the grip force as friction varies is clear, as friction may alter significantly between different materials, and for the same material under different conditions (Wilkes *et al.*, 1973). It has been found that there is a large variation in safety margin between individuals, as some individuals have a firmer grip than others, at a given slip force (Westling and Johansson, 1984). Interestingly, as noted by Westling and Johansson (1984) participants with the greatest manual dexterity employ the smallest safety margins. This variation is believed to be related to parameters within the central nervous system. Anything that blocks the transmission of impulses from the hand interferes with the feedback cycle, therefore affecting tactility and grip force control. Gloves interfere with this feedback cycle (Westling and Johansson, 1984). An investigation involving gloves, and load effect on grasp performance as a measure of tactility indicated that there was an increasing load effect, and a marginal glove effect at sub-maximal exertions.

When tactile sensitivity is reduced, the hand becomes increasingly unable to gain the necessary tactile feedback to perform a task. The most common findings are that gloves reduce strength and dexterity performance, and tactility has been said to be a possible reason for this performance decrement (Buhman *et al.*, 2000).

Dexterity

A hand performance parameter found to be adversely affected by glove use includes dexterity (Mital *et al.*, 1994; Muralidhar *et al.*, 1999). However, little information is available with regards to dexterity guiding glove selection (Shwope and Hoyle, 1985). It has been found that although fitting ease within a glove is necessary to a certain extent, and glove thickness is required for protection, excess ease and thickness cause a loss of dexterity and feeling for the worker (Williams, 1979; Tremblay, 1989). Finger and hand dexterity have been found to be reduced by 40% and 10% respectively, due to glove use. This response has been attributed to a variety of factors, the predominant of which are flexibility and glove sizing (Havenith and Vrijkotte, 1994).

Findings therefore indicate that redesigning the glove to conform to the hand, wrist and forearm, or developing a thinner glove material would be likely to improve performance with gloves (Bellingar and Slocum, 1993). This is consistent with Tremblay's (1989) findings that a tight-fitting glove will interfere the least with finger dexterity.

Speed and time to complete the task

The gloves tested in hand performance studies have differed in material composition, fit and surface texture. Therefore, the particular features of gloves associated with faster times to task completion have not been identified (Shwope and Hoyle, 1985). Griffin (1944) was the first to report that the time to move small pegs quickly from one hole to another on a board was prolonged with the use of gloves.

Bensel (1993) tested various glove types and found that, relative to bare-handed performance, the gloves which were tested limited the speed at which the work could be accomplished. If excess glove ease and thickness are afforded by the glove, the time necessary to complete the task has been found to increase (Williams, 1979; Tremblay, 1989). Wearing gloves has been found to increase task performance times by as much as 15-30% (King *et al.*, 1984; Bensel, 1993; Coates *et al.*, 2000).

Hand movement

According to Muralidhar *et al.* (1999), the range of motion that the hand is capable of is limited by glove use. Gloves interfere with a person's hand movements (Mital *et al.*, 1994), particularly precision of movement (Oborne, 1988).

Bellingar and Slocum (1993) undertook a study in which the effects of protective gloves on hand movement was assessed. Participants completed a task during which tightening/untightening of a container cap was completed. This task could be likened to the torque movement generated by participants within the current study. It was determined that the protective glove decreased the amount of abduction/adduction the hand was able to complete. It was found that protective gloves also decrease the supination/pronation movement achievable by participants. However, the glove does not notably affect extension and flexion. The hand movement decrements experienced were said to be attributable to poor fit, and the thickness and degree of flexibility of the glove material (Bellingar and Slocum, 1993).

In the investigation by Bellingar and Slocum (1993) a comparison of the hand and glove measurements revealed that the gloves were larger than the participants' hands, as hand circumference was approximately 14.2% smaller than the glove. This resulted in excess ease, and consequently, impeded motion (Bellingar, 1990).

CONCLUSION

There are therefore a number of concerns with regards to glove use (Muralidhar *et al.*, 1999). Firstly, human capability is limited to a narrow bandwidth of acceptable environmental conditions in which performance is not affected, and a number of environmental factors influence human performance. Secondly, protection from potential environmental hazards is often achieved by specific material. Thirdly, the material type and thickness have a direct effect on hand performance (Muralidhar *et al.*, 1999). Therefore, the design features of a glove emphasise either protection or performance, and it has been found that there is often a trade-off between increased safety and performance capability when donning gloves (Buhman et al., 2000). Performance decrement is a function of glove material characteristics (Bishu and Kim, 1995), and glove fit has been identified as a significant contributor to this decrement.

CHAPTER III

METHODOLOGY

INTRODUCTION

Many industries necessitate the use of industrial gloves with a pre-described level of protection, encompassing the thickness and the material of the glove. It is therefore impractical to investigate modification of these glove components. A glove component which can however be altered, and which has been highlighted in the literature requiring further ergonomic investigation is glove fit. Ill-fitting gloves have been found to increase the likelihood that workers are exposed to physical strain, and result in them being less adept at completing industrial tasks efficiently and effectively. Bradley (1969b) has shown that two glove factors, 'snugness' of fit and flexibility of material, have a strong influence on the glove user. There are limited studies which have isolated glove fit and the effect of this hand-glove interface on components of worker performance. It is imperative that information and data be collected in order to highlight the degree to which the hand-glove interface inhibits performance and increases muscular effort, therefore drawing attention to the potential of the simple intervention of addressing and adjusting glove fit for workers across all industries.

The focus of this project was two-fold. The first aim was the identification of the effect of a range of glove sizes, during a battery of performance tests, on the responses of an individual. These responses included: muscle activity, using electromyography (EMG) and perceptual responses, utilizing the rating of perceived exertion scale. The second objective was to assess the influence of glove fit on the performance attributes of industrial tasks.

EXPERIMENTAL CONCEPT

Glove fit was analysed, using a one group design, as participants donned three different glove sizes for each test to be completed. This included a best-fitting glove, a glove one size larger than best-fitting, and a glove one size smaller than best-fitting. For each size, two differing materials were tested, namely a nitrile material and a neoprene material. A barehanded condition was also tested. The conditions are illustrated in Figure 1.

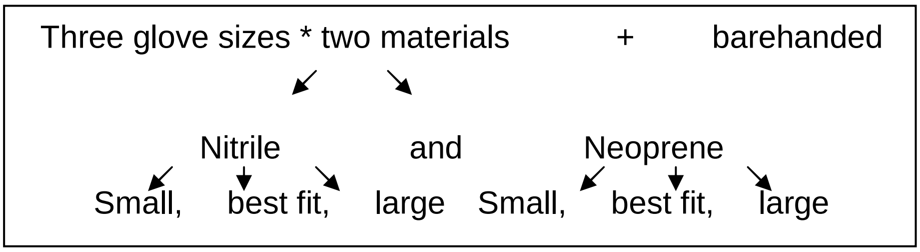

Figure 1: The seven conditions with which the battery of tests was executed.

Each test was therefore executed seven times with each of the seven gloved/barehanded conditions.

A battery of tests was designed for the study, each test being considered representative of the components of task performance in industry. Furthermore, testing components of performance, as opposed to simulating a single industrial task, allowed for greater applicability to a wide range of industries, and tasks within those industries. Performance attributes of manual tasks are considered to be manifold, and dependent on task demands, with hand performance varying considerably from one type of task, to another. The use of a battery of assessment tests is therefore preferable, in order to have a holistic performance assessment. The tests evaluated participants' maximum force-producing capabilities, in a pushing and pulling direction, torque, precision of force, tactility, speed and accuracy, and dexterity. Therefore, assessment of whether a glove impairs performance has to consider these various aspects, and cannot be described as a single measure.

The responses assessed included both psychophysical and biomechanical components, as well as specific performance criteria. This approach was employed in order to gain a holistic understanding, as recommended by Charteris *et al.* (1976), as it was expected that the different glove fit conditions would elicit different performance reactions, levels of biomechanical strain, and perceived exertion amongst the participants during the test battery.

GLOVE CHARACTERISTICS

The gloves used in the study were researched and found to be commonly used within industry. The gloves' descriptive and safety specifications can be seen in Table I. Two types of gloves, of differing materials, were tested: one glove was a green nitrile rubber glove and the second glove was a neoprene, over natural, rubber glove. Both gloves met the relevant safety standards' requirements, and were classified as chemical resistant gloves, and therefore typical industry applications for the glove use include: chemical processing plants, pharmaceutical manufacturers and hazmat clean up.

Table I: A table illustrating the descriptive and safety specifications of the gloves tested (Occupational Health and Safety, 2009).

	Nitrile rubber glove	Neoprene glove
Descriptive	Flock-lined	Flock-lined
	Anti-slip finish	'Tractor tread' grip
	0.38 mm thick	0.66 mm thick
	330.2 mm long	305 mm long
Safety	EN 388:4101	EN 388:2131
	EN 374-3	EN 374-3
	EN 374-2	EN 374-2

EN 388 provides information about the glove's mechanical (physical) performance. The following numbers assess the gloves' physical performance in four mechanical hazards.
Abrasion resistance level, ratings 0-4
Cut resistance level, ratings 0-5
Tear resistance level, ratings 0-4
Puncture resistance level, ratings 0-4
A higher number reflects a higher resistance level to that particular hazard.
EN 374-2 indicates the resistance to penetration by micro organisms, and EN 374-3 specifies the time chemicals take to break through the glove material (breakthrough time).

Figure 2: The neoprene glove (left) and nitrile glove (right).

Testing two glove types allowed for further applicability of results. However, a severe limitation to glove choice was encountered, as most gloves supplied by industrial safety equipment stockists, are available in only one size, or a very narrow range of sizes, depending on its industry application. Due to the nature of the study a broader range of sizes for a single glove type was required. Although the lack of available glove sizes for individual gloves was a significant interference for selection in the study, it further supports the necessity of the study, as clearly a range of glove sizes for optimal glove fit for individual workers, is significantly underrated. The range of glove sizes available for the experimentation included sizes 7, 8, 9 and 10.

DEPENDENT VARIABLES

Both the human operator responses and the performance responses elicited during the battery of tests were considered to be the dependent variables. The human responses were measured and monitored throughout all of the performance tests.

Human responses

The dependent variables of interest measured during the tests were muscle activity and participants' perceptual responses. Muscle activity was considered to be a necessary measure, as there is an increased risk of developing work-related musculoskeletal disorders when high levels of muscle activity are sustained (Koppelaar and Wells, 2005). Electromyography (EMG) is a biomechanical analysis tool which indirectly measures muscle activity (Stokes *et al.*, 2003). EMG has been extensively employed in Ergonomics research (Kumar and Mital, 1996). Although this method has its limitations (Feldman, 1996; Goebel, 2005), it has been reported to be a valid indicator of musculoskeletal load (Herberts *et al.*, 1980). The surface electromyography device used for this investigation was the DataLogger. The Biometrics Ltd DataLOG W4X 8 has eight channels which allow for a series of different data to be collected simultaneously. Six analogue channels were used to measure muscle activity, one for each of the selected muscles to be tested. Muscular activity is measured by attaching electrodes to the surface of the skin, and recording the changes in electrical activity in the selected muscle directly beneath them. Electrodes were attached to each of the relevant muscles, as later described in the experimental protocol, with a neutral electrode strapped to the biceps brachii muscle, reducing cross-talk.

According to Charteris *et al.* (1976), it is important to assume a holistic approach when evaluating human effort, due to the fact that a singular approach may present a biased perspective and identify only those responses which are relevant to the specific approach. Therefore, the final dependent variable was participants' ratings of perceived exertion, which were assessed in order to determine the exertion experienced by the participants. Subjective responses to the task are important as they give an indication of the perceptual balance between the task demands and the individual's capabilities. Subjective measurements were obtained using the Ratings of Perceived Exertion (RPE) scale, developed by Borg (1982) (Appendix B). This scale is designed to obtain a quantitative measure of participants' perceptions about the task being performed. The scale has numeric values, which correspond to verbal anchors, giving an indication of the perception of effort the participant feels the task required. Participants were asked to report on 'local' ratings of perceived exertion, which is the perception of muscular effort. 'Central' RPE, which represents effort exerted by the cardiovascular system (heart and lungs), was not considered, as the tasks were relatively light, occurring over a short period of time, and therefore not expected to impose excessive physiological stress on the participant.

Performance responses

Force tests (pushing, pulling and precision of force)

Pushing and pulling force was measured using a uni-axal load cell (LSB-300 – 300lb). The load cell, fitted with a pushing and a pulling mechanism, was connected to the Biometrics Ltd DataLOG W4X8, by means of a single analogue channel, and calibrated accordingly. When participants exerted force, the changes in force production generated in the load cell were displayed on the laptop screen. This provided the researcher with visual feedback about the force produced, as required, during the precision of force task.

Torque test

The CYBEX ® 6000 isokinetic dynamometer was used in order to quantify participants' torque production. Isokinetic dynamometry is commonly considered to be the standard method for assessing muscle performance, and muscle output. Isokinetic dynamometers are specifically dedicated to measuring dynamic contractions (Kumar, 2004), such as the one investigated in this protocol. Equipment included the universal tool adaptor in combination with a medium-sized, convoluted knob.

Tactility (grasp force) test

The dependent variable measured during this tactility test was the intensity of grasp pressure exerted by the participant onto the objects. It was hypothesized that this grasp pressure could represent a measure of tactile sensitivity. The logic behind this is that grasping force for a certain load will be a function of the weight to be lifted and the hand conditions. The differences in grasping force for different hand conditions will therefore be directly related to the tactile sensitivity of the corresponding hand conditions (Bishu *et al.*, 1994). It has been further reasoned that when a person grasps an object, a firm grasp is made initially, followed by a slow release to reach an effort that would just hold the object. This is due to the fact that humans, being natural optimisers, always try to hold an object with as minimal effort as possible. This minimal effort for each glove condition would be a correlation of the tactile feedback that the person receives while holding the object under that gloved condition (Bishu *et al.*, 1994).

Two pressure sensors, one leading from the distal phalanx of the first digit and one leading from the distal phalanx of the second digit, were appropriately fitted to the participants' fingers (Figure 3). These were used to measure the pressure the participants exerted. Pilot tests allowed the positioning of the pressure sensors on participants' fingers to be optimally placed for the measurement of tactility. Pilot studies also ascertained the most favourable manner in which to measure the pressure. It was found that attaching pressure sensors within the gloves, as originally intended, was not optimal, as participants' precise finger placement for each glove size could not be ensured. The sensors were connected to two analogue channels of the Biometrics Ltd DataLOG W4X8 and calibrated accordingly.

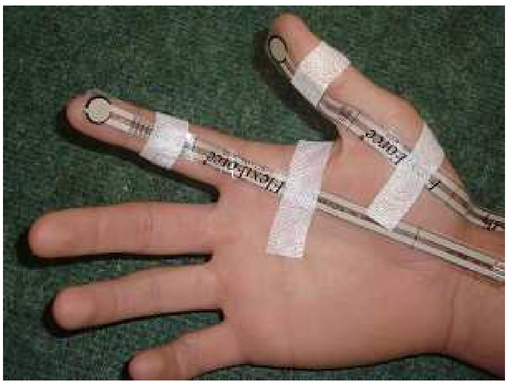

Figure 3: The placement of the pressure sensors on the first and second digits during the tactility test.

Speed and accuracy

Movement time and deviation from the target were the dependent variables assessed during this test. This is described by Fitts' Law, which is the trade-off between speed (movement time) and accuracy (deviation from the target (Fitts, 1954). This determined participants' precision performance. Performance was controlled by the index of difficulty (ID) which was determined by the ratio between movement distance and target size (Schmidt and Lee, 2005; Guastello, 2006).

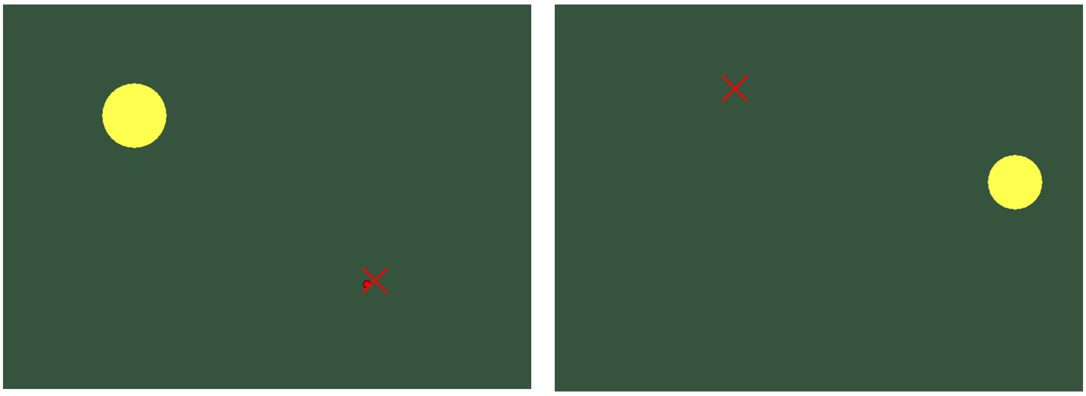

Figure 4: Example of target size and position changes for the speed and accuracy test

Participants tapped the targets on a touch screen, which interfaced with a laptop with the Fitts' test software loaded onto it. The use of tools in task performance requires controlled and skilled movements. Consequently, the interface was used, as it allowed the task to be performed using only the hand-arm segments.

Minnesota Dexterity Test

The total number of seconds it takes for participants to complete the trial translated into a measure of participants' dexterity. The complete Minnesota Dexterity Test model #32023A, as seen in Figure 5, was used in order to assess participants' dexterity abilities.

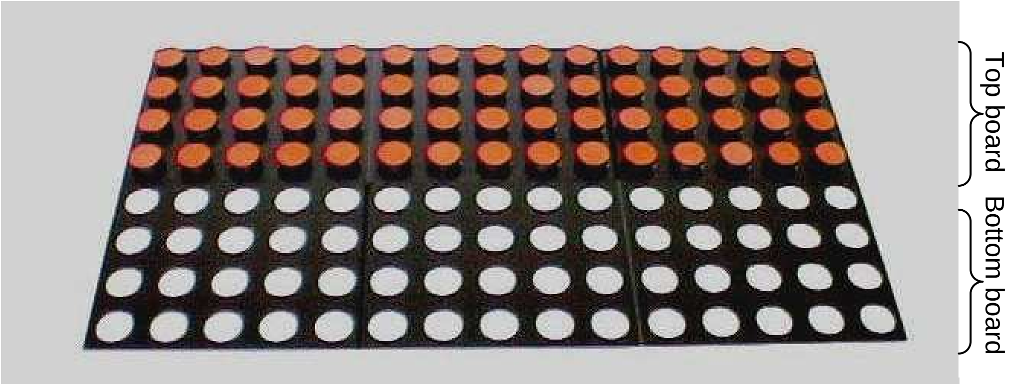

Figure 5: The starting position of the one-hand turning test.

PARTICIPANT CHARACTERISTICS

In accordance with the seven conditions that were tested, a sample of 35 male participants between the ages of 18 and 25 was selected. All the participants participated voluntarily. A sample of convenience was recruited from colleagues and students from Rhodes University.

Table II: Participants' mean anthropometric data (n=35 males) (SD denotes standard deviation).

Measurement	Mean	SD
Stature (mm)	1796.83	46.74
Hand Length (mm)	204.31	9.14
Finger Length (mm)	96.49	17.55
Palm Width (mm)	94.77	6.05
Palm Circumference (mm)	210.57	10.80

All participants were healthy and were, by self-report, free from any recent or ongoing hand or upper limb dysfunction. Participants performed all tasks with the self-reported dominant hand. Informed consent was obtained from all individuals prior to the commencement of the experimentation, using the protocol approved by the Human Kinetics and Ergonomics departmental ethics' committee. All participants were informed of the protocol and of its potential risks, and gave written consent prior to participating. Participants were inexperienced regarding industrial tasks and none of the participants was involved in daily work that requires the use of gloves. The sample was restricted however, to individuals with hand sizes of 8 or 9. This was due to the fact that participants were required to don gloves that were fitted, a size smaller and a size bigger than the fitted size, and the range of available glove sizes was limited to sizes 7, 8, 9 and 10. Therefore, in order for participants to have scope to wear a glove bigger and smaller than the best-fitting glove, the best fit needed to be a glove size of either 8 (necessitating a smaller glove size of 7, and a bigger glove size of 9), or 9 (dictating a smaller glove size of 8, and a bigger glove size of 10). Furthermore, the study was restricted to a male sample due to the limited number of females with a glove size of either size 7 or size 8.

EXPERIMENTAL PROCEDURE

The experiments were conducted in the Ergonomics Laboratory of the Human Kinetics and Ergonomics (HKE) Department at Rhodes University. The participants were required to participate in one session of two and a half hours, which included both habituation and testing.

Habituation

Participants were first introduced to, and familiarised with, the experimentation process. This habituation was designed to acquaint the participants with the experimental protocol, procedures and the equipment to be used. Additionally the participants were introduced to, and given the opportunity to, practise the tasks. Participants were fully informed of the concept and proposed execution of the research, both verbally, and in writing, with a letter of information (Appendix A). There was therefore a clear understanding of what was to be expected. In accordance with ethical standards, participants were required to sign a letter of informed consent (Appendix A).

Participants' anthropometric data were measured, therefore determining each participant's best-fitting glove, and consequently the range of glove sizes that would be used (i.e. best fit, one size larger than best fit, one size smaller than best fit). The fit between the hand and the glove was determined through the measurement of specific hand components of participants (Table III), which were compared to the same components of the gloves. Hand anthropometric measurements were taken on the dominant hand and included: digit length, hand length, hand width and palm circumference, as suggested by Larivière *et al.* (2004), and are described in Table III. Furthermore, glove fit was assessed by visually examining the amount of glove remaining at the fingertips and the gap between the webbing of the fingers and the glove. Best fit gloves had no gap and no remaining space at the ends of the fingertips (Kovacs *et al.*, 2002).

Anthropometric parameters

Anthropometric measurements were taken using a tape measure, and provided a quantitative means of describing the sample that was investigated. More importantly, however, by knowing the anthropometric dimensions, an objective measure of the fit between the participant's hand and the range of glove sizes which were donned could be assessed. Glove sizing and distinguishing the best fit glove from anthropometric hand measurements and subjective observation were refined during pilot tests.

Table III: Anthropometric measurements, and descriptions.

Anthropometric Measurement	Description of Measurement
Stature	Stature (mm) was measured using a Harpenden stadiometer. The reading was taken from the base of the stadiometer to the vertex in the sagittal plane, as the participant stood upright with the head in the Frankfurt plane.
Finger Length	The length of digit II was measured from the top of the digit to the metacarpophalangeal joints.
Hand Length	The measurement is taken from the stylion landmark to the top of digit III.
Palm Width	This was measured at the level of the metacarpophalangeal joints of the digits II and V, with the fingers adducted.
Palm	This was measured at the level of the metacarpophalangeal joints of the

Circumference	digits II and V, with the fingers adducted.

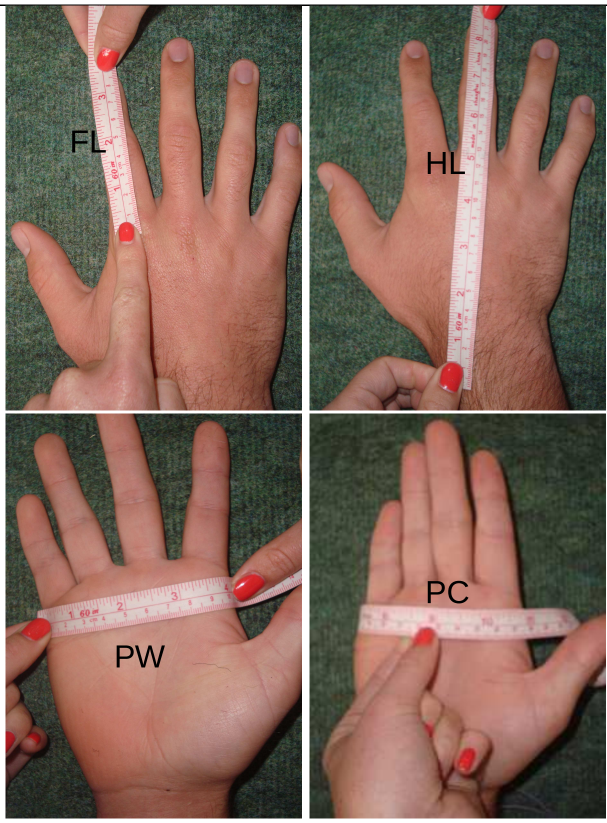

Figure 6: Illustration of the anthropometric measurements of the hand. FL: finger length, HL: hand length, PW: hand width, PC: palm circumference.

Experimentation

The electromyography unit was attached to the participant and the skin area on which the electrodes were to be adhered was cleaned with alcohol and excess hair was shaved off in order to minimise interference. Muscles were located through palpation whilst the participant contracted in various directions against resistance. The electrodes were then attached to the skin over the relevant muscles. All the hand and forearm muscles, which have been found to contribute to the outlined experimental tasks, were considered for assessment. These muscles were chosen because of their relationship with hand functionality, and their ease of measurement with surface electrodes. These included: Flexor Digitorum Superficialis (FDS), Flexor Pollicus Longus (EPL), Flexor Carpi Radialis (ECR), Flexor Carpi Ulnaris (FCU), Extensor Carpi Ulnaris (ECU) and Extensor Carpi Radialis (ECR). The muscle placements can be seen in Figure 7.

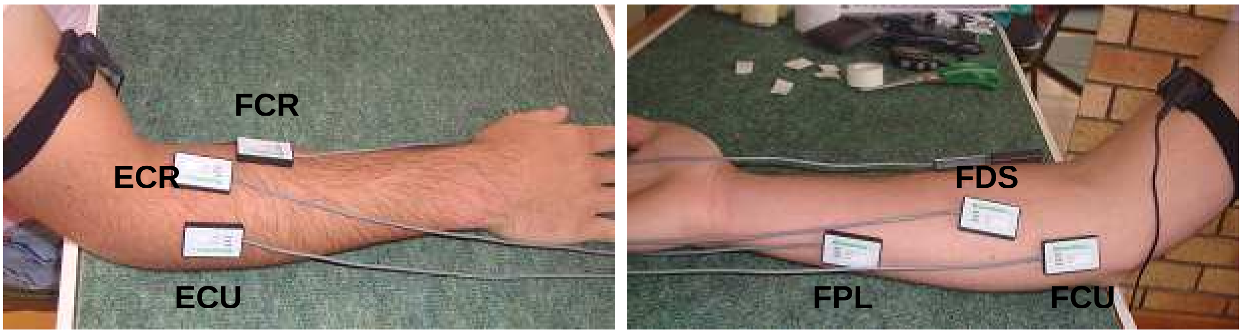

Figure 7: Electrode placement from left to right: ECR, ECU, FCR, FPL, FDS, and FCU.

These muscles were established during pilot tests, and recognised as the most active and therefore most appropriate muscles to be tested during the experimentation. Furthermore, pilot testing allowed for the application of the electrodes for optimal measurement of muscle activity of the relevant muscles to be refined. This ensured minimal interference of other muscles for data analysis. Due to the fact that surface electrodes were utilised, instead of needle electrodes, additional muscles, which are not superficial, could not be examined and were therefore excluded from the investigation.

Maximal voluntary contractions (MVCs) were then performed. EMG signals were then normalised using MVCs, such that the data is presented as a percentage of MVC, specific to each muscle being tested. This has been used successfully by several authors (Soderberg, 1992; Marras *et al.*, 1998; Garg *et al.*, 2002; Iridiastadi and Nussbaum, 2006). MVCs have been cited as a valid means of normalising EMG data, thereby allowing for changes in relative effort from the muscles to be monitored and comparisons between different glove conditions to be derived. Two successive maximal efforts, each lasting 5 seconds were performed for each of the muscles tested. A minimum of 30-seconds' rest was allowed between efforts. The execution of each MVC required participants to adopt different limb movements, as suggested by Kendall *et al.* (1993), and outlined in Table IV. Pressure was applied by the researcher directly opposite the line of contraction of the muscle being tested. This aided in eliciting the desired muscle action, as the participant produced the MVC against the resistance. Participants were given verbal encouragement in order to be motivated to exert maximal forces. Participants had the freedom to cease exertion if it was felt to be necessary, and caution was taken to prevent pain and injury.

Table IV: The postures adopted, and actions performed, by the participant and the researcher during MVC testing (Kendall *et al.*, 1993).

Muscle	Maximum Voluntary Contraction test
Flexor Digitorum Superficialis	The wrist was in neutral position, with the metacarpophalangeal joint stabilised. The interphalangeal joints of the second, third, fourth and fifth digits were flexed, with the distal interphalangeal joints extended. Pressure was exerted by the researcher against the palmer surface of the middle phalanx in the direction of extension.
Flexor Pollicus Longus	The participant's hand rested on the table for support, with the metacarpal bone and proximal phalanx of the thumb in extension. The interphalangeal joint of the thumb was flexed. The researcher applied pressure against the palmer surface of the distal phalanx in the direction of extension.
Flexor Carpi Radialis	The forearm was rested on the table for support, in slightly less than full supination. The wrist was flexed toward the radial side. Pressure was exerted by the researcher against the thenar eminence in the direction of extension toward the ulnar side.
Flexor Carpi Ulnaris	The participant's forearm was in full supination, resting on the table for support. The wrist was flexed towards the ulnar side, as the researcher applied pressure against the hypothenar eminence in the direction of extension toward the radial side.
Extensor Carpi Radialis	The forearm was in slightly less than full pronation, resting on the table for support. The researcher exerted pressure against the dorsum of the hand along the second and third metacarpal bones in the direction of flexion toward the ulnar side; as the participant extended the wrist toward the radial side.
Extensor Carpi Ulnaris	The participant's forearm was in full pronation, resting on the table for support. The participant extended the wrist toward the ulnar side, as the researcher placed pressure against the dorsum of the hand along the fifth metacarpal bone in the direction of flexion toward the radial side.

Permutations

For the experimentation, each participant performed the tests in a different order. Each test was performed with each of the seven conditions. The order of the tests was permutated followed by the order of the gloved/barehanded conditions.

Participants performed a test with a glove, and then repeated the test with a different glove, until each of the conditions had been executed. The next test was initiated; however, the glove conditions occurred in a different order to the previous test. This continued until each test in the test battery was completed. The next participant underwent the same testing procedure; however, the tests were performed in a different order to the previous participant, as well as the glove order for each test.

When the permutations were calculated, it was ensured that the maximum force tests occurred prior to the precision task (sub-maximum force). This was because the maximum forces needed to be ascertained in order to determine the 30% sub-maximum test values for each participant. Furthermore, for the tactility test, the three different masses were randomised across participants, for each glove condition. The permutations ensured that test familiarisation and potential fatigue, which could be incurred, would be negated in the results; and the execution of pilot testing allowed for the most ideal randomisation strategy to be employed, in order to keep the testing concise.

Testing

In the study, glove material and glove size have been identified as the independent variables. Participants performed each test in the test battery seven times; once barehanded, and six times whilst wearing a glove. The gloved conditions consisted of two glove materials, and participants donned three glove sizes for each material; including the best-fitting glove size, a size bigger than best-fitting, and a size smaller than best-fitting.

Maximum strength tests

Push and pull

Participants were requested to maintain a seated posture; ensuring backs were against the back rest. The centre of the chair was aligned with the handle on which the force would be exerted, and the chair was positioned such that each participant was within optimal reaching distance of the handle. The handle, which the participants grasped, was attached to a load cell, and positioned at each participant's elbow height. The researcher adjusted the chair height, accordingly. Responses were measured with the participant sitting with the forearm in a horizontal posture, parallel to the floor, in mid pronation-supination. The participant's arm was abducted between 10° and 20° with the shoulder neutrally rotated, and an elbow angle of approximately 90°, as recommended by the American Society of Hand Therapists (Mathiowetz *et al.*, 1985), and as seen in Figure 8. Posture was monitored and maintained throughout the testing condition for each participant, as it has been shown that arm posture can influence hand force. Participants were instructed to use only the arm and hand muscles to exert the desired force. The researcher monitored that this instruction was adhered to.

Figure 8: The participant's posture and handgrip during the force tests.

Participants gripped the handle, with the first digit placed parallel to the handle, and digit two through to five gripped around, and in a perpendicular direction to the handle. Participants were asked to grasp the handle and generate maximal effort for five seconds. The effort was generated in either a pulling, or a pushing direction. This was repeated three times, with a rest interval of 30 seconds allocated between each exertion. Considering that there is an important variation in strength applications, repeated measures have been found to be essential, with the majority of studies recommending the use of three recordings (Mathiowetz *et al.*, 1985). The use of the mean from three trials provides a higher reliability than with one trial. The administrator timed each repetition and indicated to the participant when to squeeze and relax for each repetition.

This protocol was repeated twice, once in a pulling direction, with the participant therefore hyper-extending the shoulder, and once again in a pushing direction, incurring shoulder flexion. For both the pulling and the pushing trials, the participant was instructed to maintain an approximate 90° elbow angle.

Torque production

Isokinetic testing was done on the CYBEX ® 6000, at a speed of $60°.s^{-1}$. This speed was used in order to best simulate the working environment, and because it is considered to be the optimal speed for strength measurements (Kumar, 2004). Participants were seated in front of the dynamometer, with the head assembly facing upwards, at an axis alignment of 90°. The height of the head assembly and distance from the participant were standardised, as the axis of the control was adjusted to be positioned in the transverse plane, aligned with the participants' xiphoid process. The participant was seated within optimal functional reach of the control. The centre of the chair was aligned with the control, and the participant's chair was raised, when necessary. Figure 9 illustrates the participants' orientation with the dynamometer.

Figure 9: The participants' posture, and the dynamometer set-up during the torque test.

The lever arm used was the universal tool adaptor. This provided the base for the force acceptance attachment (the control), which was a medium-sized, convoluted knob. This combination created the interface between the participant and the system, and moved radially about a fixed axis. The knob attachment was connected directly above the fixed axis, therefore isolating the required wrist movement for the test. The participant was instructed to grasp the knob attachment and produce maximum torque, maintaining a reasonably stationary forearm. This was achieved by abduction (external rotation) followed by adduction (internal rotation) at the radiocarpal joint. The participant performed the test by executing three maximal turns, in both directions.

Precision of force

This test consisted of a 60 second static handgrip effort at 30% MVC. The 30% selected, was that of the maximum force that was produced during the maximum force tests (both pushing and pulling). This value was decided upon, as there is considered to be a linear relationship between force produced, and the muscle activity elicited by the weakest muscle. This 30% MVC was chosen, as according to Monod's curve, and as seen in Figure 10, fatigue will not be incurred at this level, over the duration of one minute. The Monod curve was selected, as it presents the most conservative value, at 60 seconds. In order to further guarantee that no fatigue would be sustained the 30% value is below that which is recommended by Monod's curve.

The participant was given the same instruction as for the maximum force tests: however, instead of exerting maximal effort, verbal feedback was given to the participant in order to initiate the required amount of force (30% MVC). The participant was then instructed to maintain this level throughout the 60 seconds. However, once this level was reached, the participant's precision was tested, as no visual or verbal feedback was given to the participant regarding the maintained level of force. This was done in both a pulling, and a pushing direction.

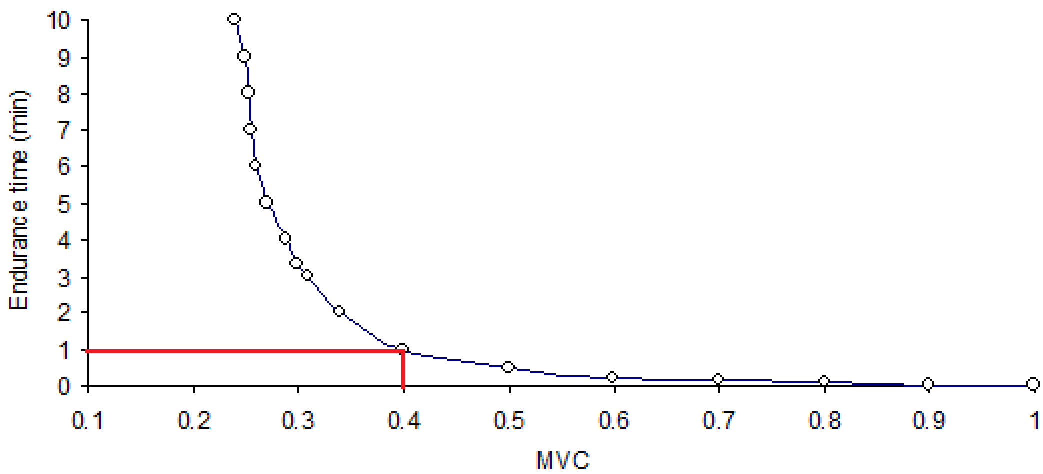

Figure 10: A graph adapted from Ma *et al.* (2009) illustrating Monod's curve, which indicates the relationship between duration of exertion and the percentage of maximum force exerted, as a function of fatigue. The red lines indicate the 40% MVC recommended for participants to exert for 60 seconds.

Grasp force as a measure of tactility

The participant was seated in front of a table, with the first and second digits in a relaxed pinch grip directly in front of the midline. The participant was instructed to reach forward and grasp the target object, which was approximately ten centimetres from the hand start position, and lift it approximately five centimetres above the table surface, as seen in Figure 11. The objects which were grasped were identical 200 ml cylindrical containers, with a length of 140 mm and a circumference of 120 mm. The unit's total mass was either 100g, 300g or 500g. This was altered using small lead balls. The objects appeared to be visually identical and therefore the only way the participants could discriminate the mass of the objects was through haptic feedback.

Figure 11: The participants' finger placement, when lifting the containers.

Speed and accuracy

A total of 25 yellow spherical targets appeared individually in a consecutive manner on a touch-screen. The participants were instructed to touch the target, as rapidly and accurately as possible using the second digit, as soon as it appeared on the touch-screen interface. After each target was selected, the same amount of time elapsed (1.5 seconds) before the next target appeared. Each task therefore lasted approximately 40 seconds (25 targets × 1.5 seconds).

The screen size, upon which the targets appeared, was 320 mm horizontally, and 280 mm, vertically. The moving field was 220 mm horizontally, and vertically. Targets jumped from point to point, and appeared 500 to 1000 ms sequentially. This limited the effects of movement speed on muscle activation. The targets appeared in a random sequence to prevent participants from predicting target location before the targets appeared. This ensured that the responses obtained were attributable to the stimulus (Schmidt and Lee, 2005).

Due to the fact that the targets appeared in a random order, the distance between the targets was dynamic, which affected the ID. To solve this effect, and keep the ID constant, the distance between the targets changed simultaneously with the size of the targets.

Minnesota Dexterity Test

This test is a frequently administered, standardised test for the evaluation of a participant's ability to move small objects various distances. The one-hand turning and placing test was administered, as instructed by the American Guidance Service (1969). A board was placed on the table, with a second board directly in front of the first board, two centimetres from the edge closest to the participant. The two boards were aligned and touching each other. One board contained 60 disks, each 3.7 centimetres in diameter, with a thickness of 1.8 centimetres. All of the disks were placed in the holes, in the top board, with the black side facing up. The object of the test was to see how quickly the participant could pick up the disks from the top board (the board furthest away from the participant), turn the disks over, therefore showing the red side of the disks, and place the disks into the holes of the bottom board (the board closest to the participant).

Participants began on the right, picking up the bottom disk, and inserting it into the top hole of the closest board, while turning the disk over to expose the other colour. Participants then picked up the next disk above the empty hole on the first board, and continued the pattern in the right column. This sequence was repeated in the second to the fifteenth columns, filling the entire bottom board.

Disks were to be fully inserted into the holes of the board before the trial was complete. If a disk was dropped, the participant was instructed to pick it up and insert it into the proper hole before the time was stopped. The participant's score was the total number of seconds taken to complete the trial.

STATISTICAL ANALYSIS

All experimental data were imported into Statistica (version 8) table. The different components of performance data were analysed separately; as well as each muscle's muscle activity responses in each test.

A one factorial repeated measures analyses of variance (ANOVA) was performed on all tests' data, except for the tactility test data, comparing the barehanded condition's responses with the best-fitting conditions' (nitrile and neoprene) responses. Additionally, two factorial (repeated measures) analyses of variance was executed on all test data, except for the tactility test data, comparing all gloved conditions' (2 materials * 3 sizes) responses.

For the tactility test data, a two factorial repeated measures analyses of variance was performed, comparing the barehanded condition's responses with the best-fitting conditions' (nitrile and neoprene) responses, and comparing the three loads (100g, 300g and 500g) within each condition. A three factorial repeated measures analyses of variance was completed comparing all gloved conditions' (2 materials * 3 sizes) responses and comparing the three loads (100g, 300g and 500g) within each condition.

These ANOVAs identified the general effects obtained for individual performance and human response measures for both glove materials (neoprene and nitrile) and glove sizes (small, best-fitting and large). *Post-hock* tukey tests processed the data further, providing specific significant differences ($p<0.05$) between conditions.

CHAPTER IV

RESULTS

INTRODUCTION

Wearing a glove can impair the effectiveness of grip force (Sudhakar *et al.*, 1988; Kinoshita, 1999), dexterity (Mital *et al.*, 1994) and functional sensation (Lyman and Groth. 1958; Kinoshita, 1999). Studies in ergonomics and biomechanical literature have also reported benefits of using gloves, enhancing work performance (Mital *et al.*, 1994; Shih and Wang, 1997).

Due to conflicting results from previous studies, and the lack of investigations which have specifically focussed on glove sizing, and work performance, this research project attempted to elucidate the effects of glove fit on the worker, and on components of task performance. A battery of tests was conducted assessing maximum pushing and pulling force, precision of force in a pushing and pulling direction, torque, tactility, speed and accuracy, and dexterity. Performance parameters, muscle activity and perceptual responses, were recorded during the tests, as participants donned gloves of three different sizes, including a best-fitting glove, a glove smaller-than-best-fitting, and a glove bigger-than-best-fitting; and two different materials for each size, including neoprene and nitrile. Participants performed the test battery a total of seven times, once barehanded, and six times with gloves (3 sizes * 2 materials).

The confidence level was set at 95% ($p<0.05$) for all results. Responses which have rendered significant results ($p<0.05$) have been illustrated by graphs, with corresponding significant p-values indicated within tables. Significant difference bars illustrated in the corresponding legends' colour denote differences between glove sizes within the same material, or differences in materials of the same size. Grey significant difference bars on the graphs indicate differences between glove materials of different sizes, and not results across a single glove component.

Results have been presented such that each test in the test battery has been divided into the responses recorded for that test; which include performance responses, muscle activity and perceptual responses. Statistics tables outline the p-values for each of the significant results ($p<0.05$), and subsequent tables and graphs further illustrate these differences.

MAXIMUM FORCE TEST

Participants were required to exert maximal force in both a pushing direction, and a pulling direction. There are inconsistent results regarding force and muscle activity as a consequence of glove use. Fleming *et al.* (1997) found that the use of work gloves increased muscle activity and accelerated fatigue when participants wearing such gloves were compared with participants performing the same tasks without gloves. Sudhakar *et al.* (1988) reported that muscle activity is unaffected by glove conditions.

This study considered muscle activity during force tests, as force is an integral component of task execution. Force was recorded in Newtons (N), and muscle activity responses were evaluated. Subsequent to each maximal effort with a different glove condition, participants' ratings of perceived exertion were noted.

Performance responses

Table V: Mean maximum force (N) exerted in a pushing and pulling direction for each condition. Standard deviations indicated in brackets.

	Bare-handed	Nitrile			Neoprene		
		Small	Best fit	Large	Small	Best fit	Large
Pulling (N)	-264.20 (±89.39)	-257.38 (±85.57)	-261.22 (±91.51)	-258.98 (±90.14)	-260.28 (±78.33)	-267.21 (±89.52)	-258.18 (±86.10)
Pushing (N)	234.75 (±80.27)	230.07 (±80.06)	222.73 (±76.26)	228.21 (±89.08)	226.72 (±75.75)	235.78 (±81.63)	223.01 (±72.86)

Glove fit and glove material type had no apparent effect on participants' force (N) generation, as no significant differences ($p<0.05$) were calculated between any conditions during either the pulling or pushing force tests.

Muscle activity

Muscle activity responses were relativised to the maximal voluntary contractions (MVC) that were performed for each muscle. Therefore, muscle activity results are presented as a percentage of MVC.

Table VI: Mean muscle activity (mV) measured for each muscle for each condition during the maximum pushing and pulling test. Standard deviations indicated in brackets. FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

	Muscle	Bare-handed	Nitrile			Neoprene		
			Small	Best fit	Large	Small	Best fit	Large
Pulling (mV)	FDS	38.64 (±16.71)	38.92 (±15.79)	36.57 (±18.11)	38.39 (±17.22)	38.50 (±14.47)	39.20 (±14.56)	39.56 (±15.90)
	FPL	36.40 (±15.06)	36.91 (±14.13)	35.95 (±16.98)	35.82 (±14.55)	37.25 (±15.45)	38.70 (±16.32)	38.67 (±16.11)
	ECU	22.26 (±15.68)	24.12 (±17.18)	22.55 (±12.80)	26.67 (±20.15)	23.54 (±19.08)	25.17 (±17.60)	21.44 (±12.87)
	ECR	28.63 (±17.68)	30.38 (±17.55)	30.08 (±16.74)	34.81 (±21.79)	28.99 (±18.34)	31.03 (±16.31)	27.23 (±16.20)
	FCU	35.07 (±15.08)	36.63 (±14.98)	35.58 (±13.19)	34.36 (±14.61)	35.34 (±15.98)	36.66 (±17.35)	37.09 (±15.63)
	FCR	45.58 (±22.90)	46.27 (±18.35)	42.98 (±21.40)	45.56 (±17.68)	46.56 (±19.52)	49.79 (±21.65)	44.87 (±20.08)
Pushing (mV)	FDS	22.22 (±10.85)	23.76 (±12.36)	23.56 (±14.12)	23.36 (±12.50)	22.39 (±11.54)	20.78 (±10.72)	22.63 (±13.08)
	FPL	25.79 (±11.41)	26.69 (±12.18)	25.70 (±10.84)	27.05 (±12.10)	25.93 (±11.23)	25.96 (±12.41)	25.31 (±11.01)
	ECU	56.99 (±25.36)	51.74 (±23.75)	50.16 (±23.27)	50.19 (±24.23)	51.47 (±21.96)	51.91 (±24.80)	50.65 (±25.63)
	ECR	38.70 (±30.50)	38.39 (±28.39)	37.66 (±27.28)	35.46 (±24.66)	38.98 (±29.72)	38.02 (±29.23)	37.93 (±29.29)
	FCU	22.34 (±13.37)	21.03 (±13.12)	21.58 (±14.28)	21.85 (±14.39)	21.12 (±13.97)	21.23 (±14.85)	21.71 (±14.04)
	FCR	16.74 (±8.97)	17.77 (±9.55)	18.76 (±11.89)	19.01 (±11.84)	17.53 (±9.14)	17.52 (±9.16)	17.53 (±9.24)

Table VII: Two-factorial analysis of variance of the maximum pushing and pulling for the factors: glove size (small, best fit and large) and material (neoprene and nitrile). FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

		Degrees of freedom	F	p
Pulling: ECU	Material	1	1.08083	0.305850
	Size	2	0.02145	0.978781
	Material*Size	*2*	*4.43733*	*0.015441*
Pulling: ECR	Material	*1*	*5.0369*	*0.031432*
	Sizes	2	0.4505	0.639205
	Material*Size	*2*	*4.4981*	*0.014633*
Pulling: FCR	Material	1	2.5326	0.120773
	Size	2	0.6109	0.545797
	Material*Size	*2*	*3.7246*	*0.029177*
Pushing: FDS	Material	*1*	*4.3774*	*0.043958*
	Size	2	0.4293	0.652689
	Material*Size	2	0.5322	0.589721

Table VIII: One-factorial analysis of variance of the maximum pushing and pulling for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition). FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

		Degrees of freedom	F	p
Pulling: FCR	Condition	*2*	*4.3914*	*0.016082*
Pushing: ECU	Condition	*2*	*4.3274*	*0.017020*
Pushing FCR	Condition	*2*	*70.4150*	*0.0000000002*

As seen in Table VII, an overall significant difference (p<0.05) was found between the combination of all glove sizes and materials during the maximum pulling task for the Extensor Carpi Ulnaris, and between all materials during the maximum pushing task for the Flexor Digitorum Superficialis. However, a post-hok tukey analysis did not reveal any specific significant differences between conditions.

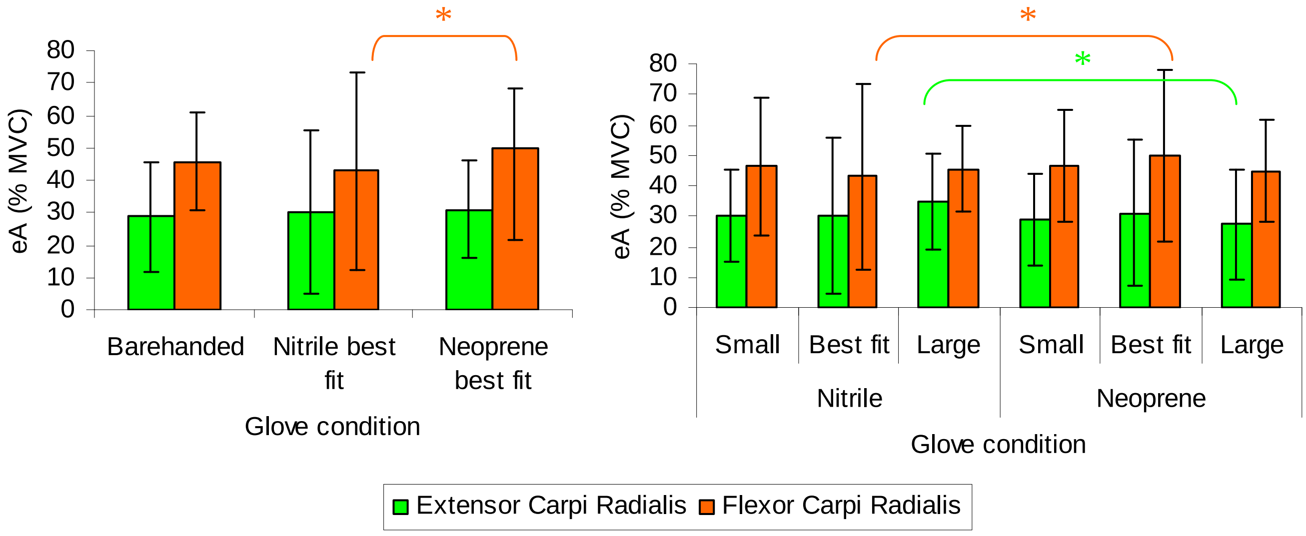

Figure 12: Comparison of the muscle activity responses between conditions (left) and materials and sizes (right), as a % of MVC, during the maximum **pulling** force test (* denotes a statistically significant difference, $p<0.05$).

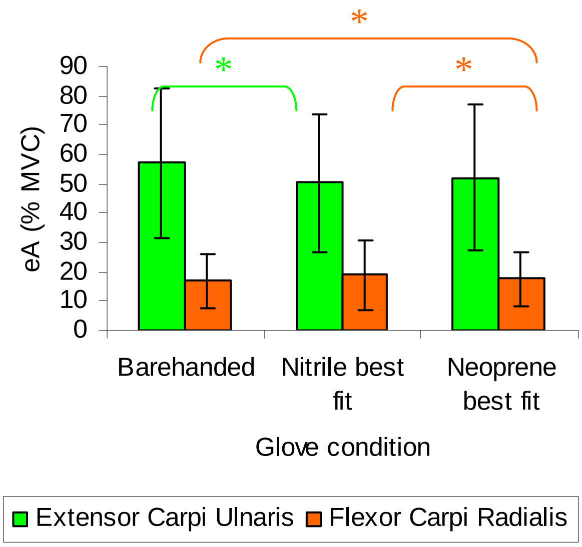

Figure 13: Comparison of the muscle activity responses between conditions, as a % of MVC, during the maximum **pushing** force test (* denotes a statistically significant difference, $p<0.05$).

Figure 12 and Figure 13 show significant differences ($p<0.05$) produced during the maximum force tests. For the maximum pulling test, a significant difference ($p<0.05$) was calculated between the nitrile and neoprene best-fitting gloves for the Flexor Carpi Radialis muscle, as well as between the large nitrile glove and large neoprene glove for the Extensor Carpi Radialis muscle.

The maximum pushing force test elicited a significant difference ($p<0.05$) between the barehanded condition and the neoprene best fit glove; and between the nitrile best fit glove and the neoprene best fit glove for the Flexor Carpi Radialis muscle. There was a significant difference ($p<0.05$) between the barehanded condition and the nitrile best fit glove for the Extensor Carpi Ulnaris muscle.

Perceptual responses (Rating of perceived exertion)

Table IX: Participants' ratings of perceived exertion for the maximum pushing and pulling tasks for each condition. Standard deviations indicated in brackets.

Test	Bare-handed	Nitrile			Neoprene		
		Small	Best fit	Large	Small	Best fit	Large
Maximum push	13 (±3)	14 (±4)	13 (±3)	13 (±3)	13 (±3)	13 (±3)	13 (±3)
Maximum pull	13 (±3)	13 (±3)	13 (±3)	13 (±3)	13 (±3)	13 (±3)	13 (±3)

Glove fit and glove material type had no apparent effect on the ratings of perceived exertion (RPE) during the maximal pushing and pulling force tests.

MAXIMUM TORQUE TEST

Participants' torque was also considered, as this is a relevant component of task performance within industry. The performance responses included peak torque (Nm), the total work (Nm) and the average power (J) achieved, during which muscle activity was measured. Following each torque exertion with a glove condition, participants' ratings of perceived exertion were recorded.

Performance responses

Table X: Mean maximum torque test responses, including participants' peak torque (Nm), total work (Nm) and average power (J) for each condition. Standard deviations indicated in brackets.

	Torque results	Bare-handed	Nitrile			Neoprene		
			Small	Best fit	Large	Small	Best fit	Large
Conc. Ext. rotation	Peak torque (Nm)	5.68 (±1.66)	8.77 (±2.14)	8.81 (±1.80)	8.03 (±1.87)	8.39 (±1.50)	8.77 (±1.98)	8.29 (±2.27)
	Total work (Nm)	3.61 (±1.33)	5.65 (±1.70)	5.68 (±1.62)	5.32 (±1.62)	5.55 (±1.63)	5.74 (±1.55)	5.48 (±1.90)
	Average power (J)	4.13 (±1.43)	6.26 (±1.77)	6.48 (±1.61)	5.97 (±1.70)	6.35 (±1.43)	6.58 (±1.57)	6.10 (±1.70)
Conc. Int. rotation	Peak torque (Nm)	6.77 (±2.06)	9.00 (±2.28)	9.65 (±2.43)	8.96 (±2.40)	8.84 (±1.97)	10.00 (±3.25)	9.26 (±2.29)
	Total work (Nm)	3.94 (±1.59)	5.42 (±1.61)	6.10 (±1.70)	5.77 (±1.67)	5.71 (±1.75)	6.16 (±1.75)	5.74 (±1.71)
	Average power (J)	4.52 (±1.52)	6.55 (±1.82)	7.32 (±2.12)	6.65 (±1.84)	6.74 (±1.65)	7.35 (±1.92)	6.65 (±1.72)

Table XI: Two-factorial analysis of variance of the torque results for the factors: glove size (small, best fit and large) and material (neoprene and nitrile).

		Degrees of freedom	F	p
Peak torque: concentric ext. rotation	Material	1	0.0983	0.756084
	Size	*2*	*4.9381*	*0.010343*
	Material*Size	2	1.3468	0.267830
Peak torque: concentric int. rotation	Material	1	0.3876	0.538258
	Size	*2*	*4.5404*	*0.014582*
	Material*Size	2	0.6439	0.528806
Total work: concentric int. rotation	Material	1	0.4548	0.505218
	Size	*2*	*3.9182*	*0.025156*
	Material*Size	2	0.4538	0.637341
Average power: concentric ext. rotation	Material	1	0.4726	0.497079
	Size	*2*	*4.1480*	*0.020543*
	Material*Size	2	0.0082	0.991831
Average power: concentric int. rotation	Material	1	0.1542	0.697284
	Size	*2*	*7.4446*	*0.001294*
	Material*Size	2	0.1676	0.846088

Table XI shows an overall significant difference ($p<0.05$) that was found between all of the glove sizes for the peak torque responses during external rotation, however, a post-hok tukey analysis did not reveal any specific significant differences between conditions.

Table XII: One-factorial analysis of variance of the torque results for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition).

		Degrees of freedom	F	p
Peak torque: concentric ext. rotation	Condition	*2*	*75.3682*	*p<0.05*
Peak torque: concentric int. rotation	Condition	*2*	*28.9073*	*0.000000002*
Total work: concentric ext. rotation	Condition	*2*	*82.4707*	*p<0.05*
Total work: concentric int. rotation	Condition	*2*	*48.8080*	*0.0000000000003*
Avg. power: concentric ext. rotation	Condition	*2*	*94.7754*	*p<0.05*
Avg. power: concentric int. rotation	Condition	*2*	*65.0000*	*0.000000000000001*

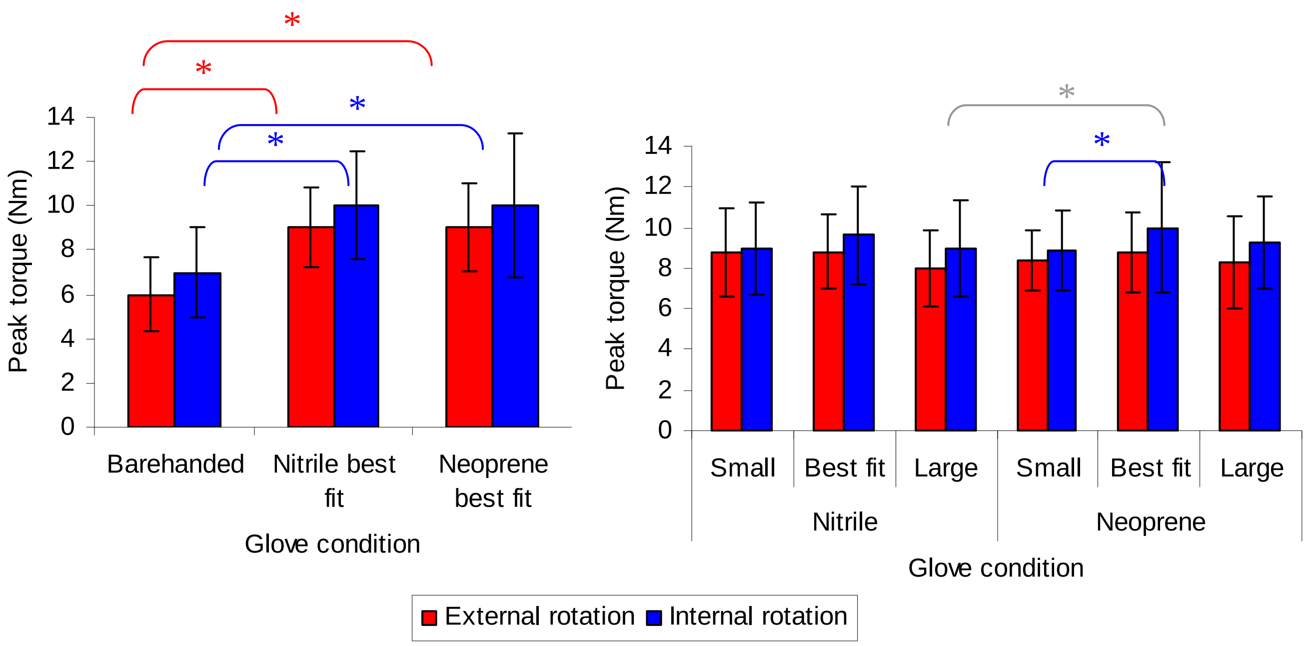

Figure 14: Comparison of the peak torque (Nm) responses between conditions (left) and materials and sizes (right) during the torque test (* denotes a statistically significant difference, p<0.05).

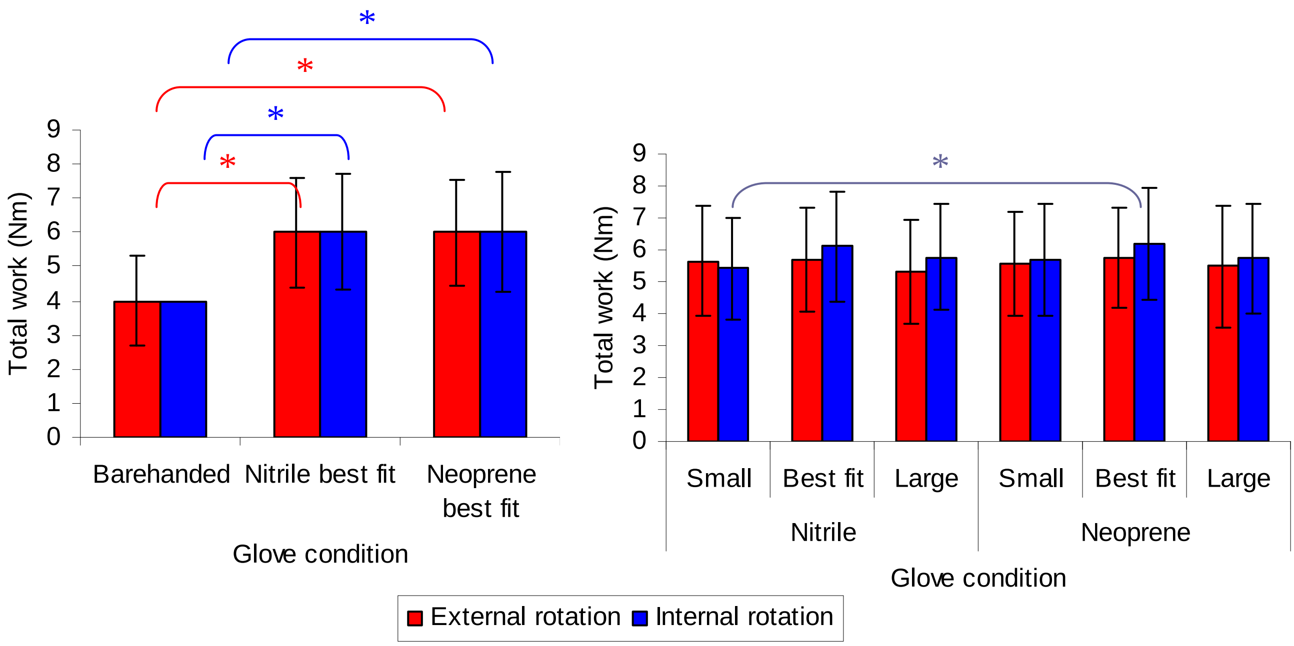

Figure 15: Comparison of the total work (Nm) responses between conditions (left) and materials and sizes (right) during the torque test (* denotes a statistically significant difference, p<0.05).

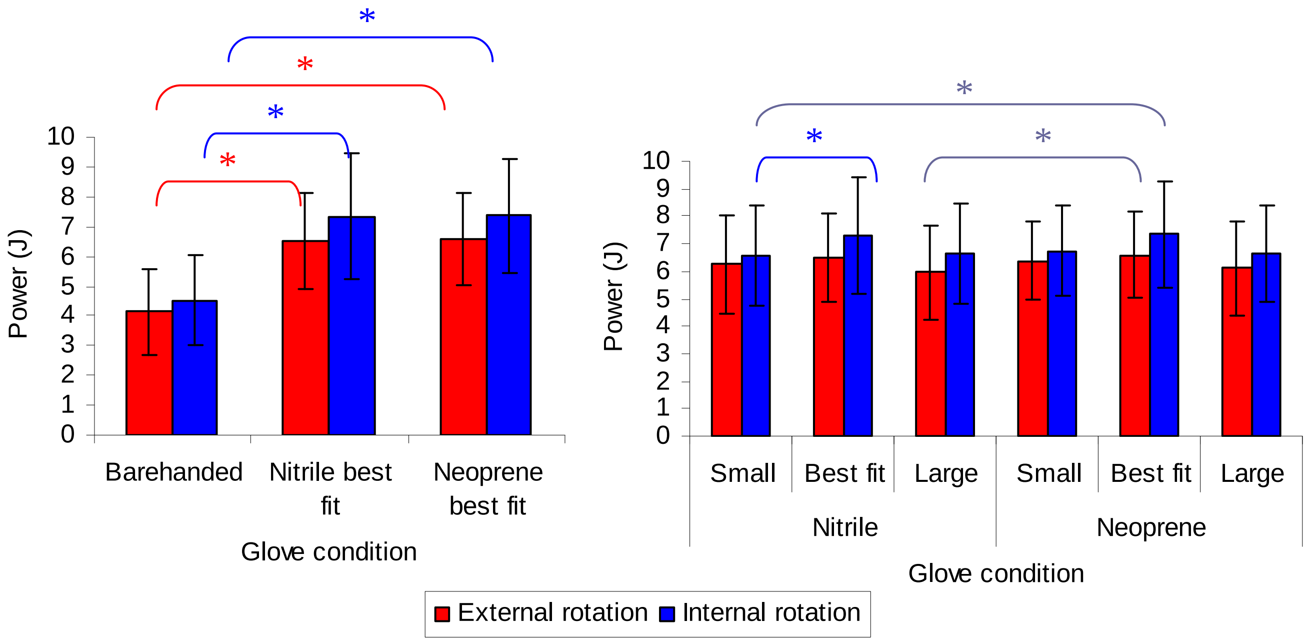

Figure 16: Comparison of the total work (Nm) responses between conditions (left) and materials and sizes (right) during the torque test (* denotes a statistically significant difference, p<0.05)

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Figure 14, Figure 15 and Figure 16 illustrate participants' torque results, quantified by peak torque, total work and average power respectively. All of the results indicate significant differences (p<0.05) between the barehanded condition, and the best-fitting nitrile and best-fitting neoprene conditions, for both external and internal rotation.

Significant differences (p<0.05) were calculated for peak torque between the best-fitting and the small neoprene gloves and between the best-fitting and the large neoprene gloves (Figure 14). Significant differences (p<0.05) were found between conditions for the average power results, as seen in Figure 16. The best-fitting nitrile glove condition yielded significantly greater results than the small nitrile glove condition.

Muscle activity

Table XIII: Mean muscle activity (mV) measured for each muscle for each condition during the torque test. Standard deviations indicated in brackets. FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

Muscle	Bare-handed	Nitrile			Neoprene		
		Small	Best fit	Large	Small	Best fit	Large
FDS	18.18 (±10.28)	18.48 (±7.26)	17.41 (±10.44)	20.40 (±9.77)	17.64 (±9.41)	18.94 (±12.13)	21.79 (±12.61)
FPL	22.06 (±9.25)	21.90 (±9.15)	21.93 (±11.90)	23.46 (±10.64)	22.45 (±9.76)	23.17 (±10.51)	23.37 (±8.72)
ECU	27.91 (±10.86)	31.33 (±12.14)	31.80 (±15.04)	32.93 (±15.09)	33.15 (±14.28)	32.64 (±14.19)	32.64 (±12.72)
ECR	21.84 (±12.47)	23.34 (±10.86)	24.80 (±20.45)	25.79 (±19.33)	26.13 (±15.47)	23.82 (±14.06)	28.30 (±18.65)
FCU	17.87 (±7.73)	17.81 (±7.08)	17.72 (±10.03)	19.33 (±9.07)	17.69 (±7.22)	18.58 (±10.77)	19.45 (±8.95)
FCR	12.50 (±5.90)	12.52 (±6.01)	12.01 (±6.92)	13.40 (±6.31)	13.19 (±6.16)	13.07 (±6.13)	13.60 (±6.65)

Table XIV: Two-factorial analysis of variance of the muscle activity results from the torque test for the factors: glove size (small, best fit and large) and material (neoprene and nitrile). FDS = Flexor Digitorum Superficialis

		Degrees of freedom	F	p
FDS	Material	1	0.7429	0.394759
	Size	*2*	*5.3996*	*0.006661*
	Material*Size	2	1.4432	0.243311

Table XV: One-factorial analysis of variance of the muscle activity results from the torque test for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition). ECU = Extensor Carpi Ulnaris

		Degrees of freedom	F	p
ECU	Condition	*2*	*5.9312*	*0.004223*

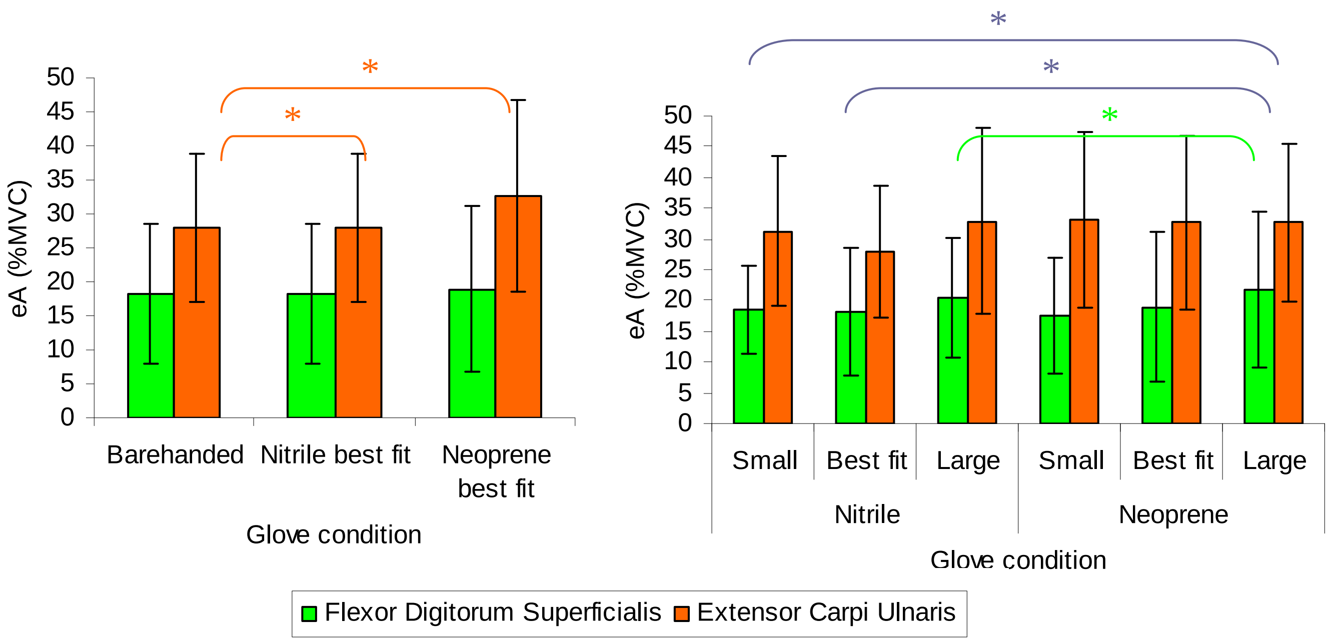

Figure 17: Comparison of the muscle activity (mV) responses between conditions (left) and materials and sizes (right) during the torque test (* denotes a statistically significant difference, p<0.05).

Figure 17 illustrates a significant difference (p<0.05) established between the nitrile large glove, and the neoprene large glove for the Flexor Digitorum Superficialis muscle during the maximum torque task. For the Extensor Carpi Ulnaris muscle, significant differences (p<0.05) were determined between the barehanded condition and the nitrile best fit glove, and the barehanded condition and the neoprene best fit glove.

Perceptual responses (Rating of perceived exertion)

Table XVI: Participants' ratings of perceived exertion for the torque test for each condition. Standard deviations indicated in brackets.

Bare-handed	Nitrile			Neoprene		
	Small	Best fit	Large	Small	Best fit	Large
11 (±3)	11(±3)	11 (±3)	11(±3)	11 (±3)	11(±3)	11(±3)

PRECISION OF FORCE TEST

Precision of force application was measured by the degree to which participants deviated (over/under compensated) from a constant force over a minute. This was calculated by calculating the relative trend of the force exertion, and the muscle activity followed over the minute. Furthermore, the mean deviation from the trend was calculated in order to further quantify participants' force precision. This was done in both a pushing direction and in a pulling direction.

Performance responses

Table XVII: Comparison of participants' force for a) the force trend between conditions. The force trend (%) is the relative trend the force exertion followed over one minute. And b) the mean deviation from this trend (N).

		Bare-handed	Nitrile			Neoprene		
			Small	Best fit	Large	Small	Best fit	Large
Force trend (%.min^{-1})	Pulling	-11.84 (±19.54)	-9.50 (±19.13)	-2.46 (±27.27)	-0.89 (±22.97)	-7.77 (±19.61)	-3.72 (±20.13)	-5.96 (±28.42)
	Pushing	-6.95 (±25.85)	-8.83 (±27.35)	-9.33 (±24.13)	-18.50 (±24.07)	-18.86 (±23.75)	-7.61 (±23.38)	-9.70 (±33.77)
Deviation from trend (N)	Pulling	44.65 (±30.20)	50.85 (±36.48)	38.60 (±25.50)	56.41 (±28.25)	44.30 (±29.43)	51.61 (±35.12)	58.50 (±30.17)
	Pushing	51.49 (±32.30)	49.76 (±37.65)	42.56 (±34.17)	56.28 (±32.52)	49.21 (±36.58)	55.89 (±40.99)	60.57 (±33.14)

Table XVIII: One-factorial analysis of variance of the force trend (%.min^{-1}) for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition).

		Degrees of freedom	F	p
Precision of force trend: pushing (%.min^{-1})	Material	1	0.00321	0.955164
	Size	2	1.55964	0.217637
	Material*Size	*2*	*3.37925*	*0.039888*

An overall significant difference (p<0.05) was found between the combination of all glove sizes and materials during the precision of force pushing task for the force trend (%.min-1) for the force (N) generated, as indicated in Table XVIII; however, a post-hok tukey analysis did not reveal any specific significant differences between conditions. No further significant differences (p<0.05) were determined for the precision of force performance results.

Muscle activity

Table XIX: Comparison of participants' muscle activity responses for a) the force trend between conditions. The force trend (%) is the relative trend the force exertion followed over one minute. And b) the mean deviation from this trend (mV).

		Muscle	Bare-handed	Nitrile			Neoprene		
				Small	Best fit	Large	Small	Best fit	Large
Force trend ($\%.min^{-1}$)	Pulling	FDS	1.40 (±30.37)	3.74 (±23.44)	0.37 (±34.73)	-4.79 (±39.10)	-10.05 (±26.85)	-7.69 (±25.53)	-4.70 (±30.29)
		FPL	9.75 (±45.43)	-2.42 (±34.31)	13.15 (±36.74)	-6.71 (±36.21)	-4.72 (±32.29)	-4.81 (±35.67)	-1.23 (±36.28)
		ECU	8.10 (±30.62)	-4.78 (±47.45)	1.15 (±47.80)	8.94 (±47.62)	1.78 (±37.68)	0.07 (±43.31)	-3.17 (±46.94)
		ECR	19.24 (±53.63)	20.20 (±62.35)	9.62 (±73.42)	30.88 (±45.63)	24.85 (±52.78)	5.18 (±59.59)	15.94 (±59.64)
		FCU	6.67 (±48.04)	5.20 (±32.91)	8.62 (±45.43)	0.83 (±42.42)	-3.39 (±28.75)	1.51 (±33.78)	0.75 (±37.06)
		FCR	7.89 (±41.93)	8.95 (±52.67)	17.76 (±51.82)	24.03 (±40.86)	13.75 (±37.24)	11.63 (±42.78)	10.88 (±42.66)
	Pushing	FDS	-5.40 (±42.79)	-17.34 (±55.08)	-15.00 (±39.31)	-13.30 (±47.15)	-8.94 (±32.76)	-9.35 (±30.39)	-5.41 (±41.34)
		FPL	-5.11 (±30.89)	-3.74 (±34.70)	-7.43 (±25.69)	-5.74 (±41.25)	-3.81 (±29.07)	-4.42 (±25.88)	-2.15 (±35.16)
		ECU	6.79 (±0.00)	5.61 (±37.67)	2.54 (±34.16)	-4.06 (±28.70)	-14.02 (±29.43)	0.64 (±32.99)	8.47 (±44.73)
		ECR	4.25 (±35.28)	-2.46 (±44.54)	-4.35 (±41.36)	-4.60 (±46.85)	-19.01 (±39.57)	-2.75 (±36.44)	1.19 (±56.48)
		FCU	-8.37 (±35.10)	-12.20 (±41.69)	-9.17 (±27.79	-10.21 (±41.29)	-5.88 (±37.28)	-8.27 (±33.50)	-2.10 (±39.48)
		FCR	1.47 (±34.70)	-.97 (±32.33)	-4.29 (±29.05)	5.86 (±38.79)	-12.45 (±27.53)	-2.22 (±26.00)	1.21 (±42.21)
Deviation from trend (mV)	Pulling	FDS	20.41 (14.06)	22.75 (14.57)	20.57 (14.18)	25.93 (17.61)	-10.05 (26.85)	-7.69 (25.53)	-4.70 (30.29)
		FPL	19.17 (13..92)	18.45 (11.20)	17.02 (10.20)	20.73 (11.97)	-4.72 (32.29)	-4.81 (35.67)	-1.23 (36.28)
		ECU	6.43 (5.92)	8.99 (9.10)	9.34 (16.14)	9.26 (9.36)	1.78 (37.68)	0.07 (43.31)	-3.17 (46.94)
		ECR	10.56 (13.35)	9.59 (9.20)	9.06 (9.05)	11.11 (13.02)	24.85 (52.78)	5.18 (59.49)	15.94 (59.64)
		FCU	18.25 (14.74)	19.57 (13.39)	16.44 (10.76)	20.40 (12.61)	-3.39 (28.75)	1.51 (33.78)	0.75 (37.06)
		FCR	18.20 (14.12)	16.94 (13.09)	13.56 (9.60)	16.14 (11.76)	13.75 (37.24)	11.63 (42.78)	10.88 (42.66)
	Pushing	FDS	13.02 (13.59)	14.93 (17.35)	13.74 (15.10)	21.01 (25.90)	-8.94 (32.76)	-9.35 (30.39)	-5.41 (41.34)
		FPL	12.12 (7.79)	15.49 (10.08)	14.30 (10.58)	17.03 (10.69)	-3.81 (29.76)	-4.42 (25.88)	-2.15 (35.16)
		ECU	36.70 (24.99)	44.02 (39.96)	36.74 (34.99)	48.15 (40.08)	-14.02 (29.43)	0.64 (32.99)	8.47 (44.73)
		ECR	17.82 (16.58)	26.75 (30.54)	21.62 (25.68)	27.43 (41.77)	-19.01 (39.57)	-2.75 (36.44)	1.19 (56.48)
		FCU	9.44 (7.67)	11.30 (10.43)	11.67 (12.01)	13.92 (12.74)	-5.88 (37.28)	-8.27 (33.50)	-2.10 (39.48)
		FCR	7.86 (5.18)	9.57 (9.19)	8.61 (8.50)	11.51 (10.79)	-12.45 (27.53)	-2.22 (26.00)	1.21 (42.21)

Table XX: Two-factorial analysis of variance of the muscle activity responses for the force trend (%.min^{-1}) and deviation from the trend (mV) for the factors: glove size (small, best fit and large) and material (neoprene and nitrile). FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

		Degrees of freedom	F	p
30% force pulling, force trend: FDS	Material	*1*	*6.631171*	*0.014544*
	Size	2	0.052041	0.949328
	Material*Size	2	1.771271	0.177875
30% force pulling, force trend: FPL	Material	1	2.324352	0.136612
	Size	2	1.529063	0.224097
	Material*Size	*2*	*3.764261*	*0.028153*
30% force pushing, force trend: ECU	Material	1	0.529097	0.471966
	Size	2	0.852433	0.430882
	Material*Size	*2*	*4.756504*	*0.011656*
30% force pulling, dev from trend: FCU	Material	1	0.7853	0.381757
	Size	*2*	*3.9686*	*0.023435*
	Material*Size	2	0.0381	0.962594
30% force pushing, dev from trend: FDS	Material	1	0.55773	0.460310
	Size	2	2.80549	0.067492
	Material*Size	*2*	*3.33402*	*0.041564*
30% force pushing, dev from trend: FCU	Material	1	3.72705	0.061912
	Size	*2*	*3.24370*	*0.045132*
	Material*Size	2	1.57609	0.214242

Table XXI: One-factorial analysis of variance of the muscle activity responses for the force trend (%.min^{-1}) for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition). FCU = Flexor Carpi Ulnaris

		Degrees of freedom	F	p
30% force pushing, dev from trend: FCU	Condition	*2*	*26.21929*	*0.00000000362*

Table XX shows an overall significant difference (p<0.05) was found between the glove material conditions during the precision of force pulling task for the force trend (%.min^{-1}) for the Flexor Digitorum Superficialis; and between all sizes for the deviation from the trend (mV) for the pulling task for the Flexor Carpi Ulnaris; however, a post-hok tukey analysis did not reveal any specific significant differences between conditions.

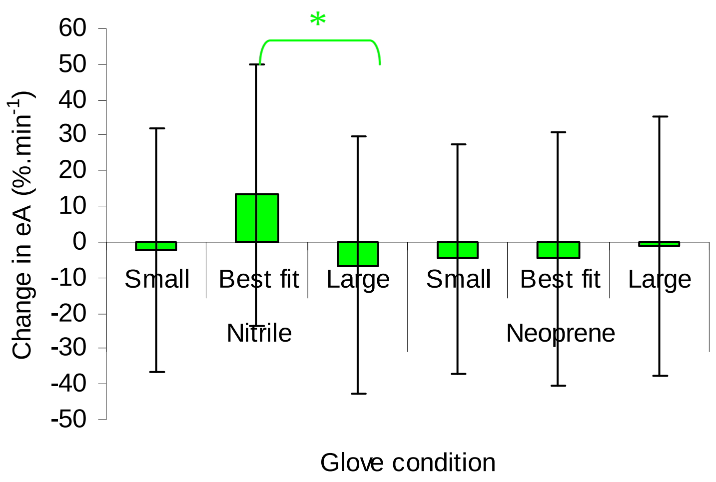

Figure 18: The force trend as a % over a minute during the **pulling** precision of force test for the Flexor Pollicus Longus muscle comparing the materials and sizes (* denotes a statistically significant difference, $p<0.05$).

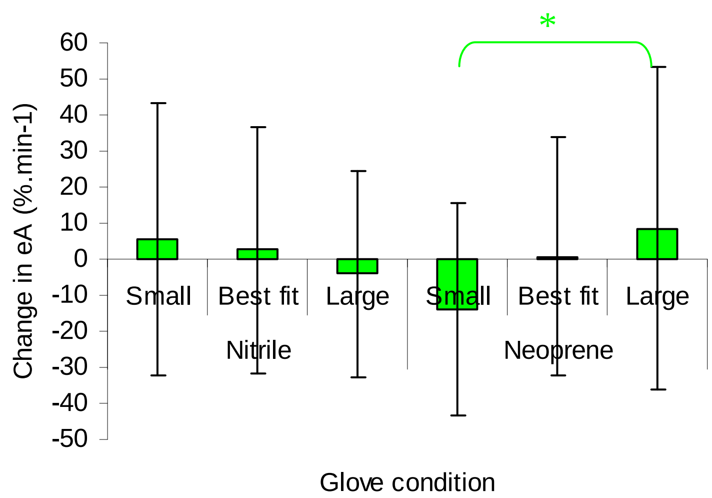

Figure 19: The force trend as a % over a minute during the **pushing** precision of force test for the Extensor Carpi Ulnaris muscle comparing the materials and sizes (* denotes a statistically significant difference, $p<0.05$).

Figure 18 and Figure 19 compare the force trends across each gloved condition for the precision of force test for the pulling task and the pushing task, respectively.

Figure 18 shows a significant difference ($p<0.05$) between the nitrile best fit and the nitrile large gloves for the Flexor Pollicus Longus muscle and Figure 19 illustrates a significant difference ($p<0.05$) between the neoprene small and the neoprene large gloves for the Extensor Carpi Ulnaris.

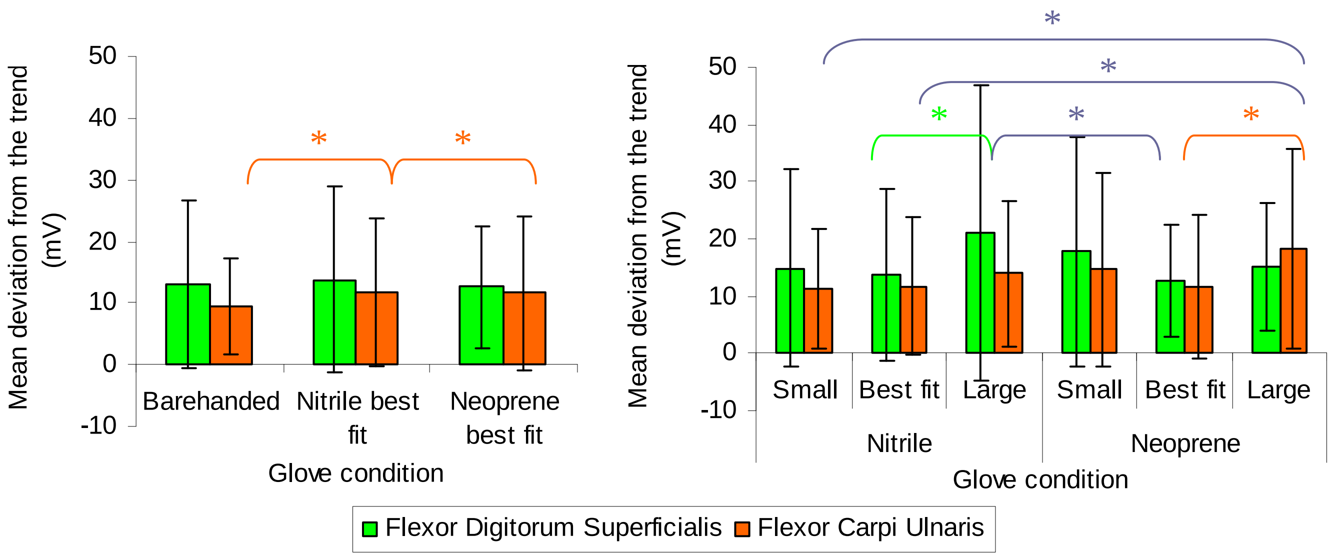

Figure 20: The muscle activity's mean deviation from the force trend (mV) during the **pushing** precision of force test for the Flexor Digitorum Superficialis and Flexor Carpi Ulnaris muscles, comparing the materials and sizes (* denotes a statistically significant difference, $p<0.05$).

The mean deviation from the trend (mV) during the precision of force pushing task for the Flexor Digitorum Superficialis and the Flexor Carpi Ulnaris can be seen in Figure 20.

For the Flexor Digitorum Superficialis muscle, a significant difference ($p<0.05$) was calculated between the best fit nitrile and the large nitrile gloves. Significant differences ($p<0.05$) were found between the barehanded condition and the nitrile best fit glove, between the nitrile best fit and the neoprene best fit, and between the neoprene best fit and neoprene large gloves, for the Flexor Carpi Ulnaris muscles.

Perceptual responses (Rating of perceived exertion)

Table XXII: Participants' ratings of perceived exertion for the precision of force maximum pushing and pulling tasks for each condition. Standard deviations indicated in brackets.

Test	Bare-handed	Nitrile			Neoprene		
		Small	Best fit	Large	Small	Best fit	Large
30% push	12 (±3)	13 (±3)	12 (±3)	13 (±3)	12 (±3)	12 (±3)	13 (±3)
30% pull	11 (±3)	12 (±3)	11 (±3)	12 (±3)	12 (±3)	11 (±3)	12 (±3)

Glove fit and glove material type had no apparent effect on the ratings of perceived exertion (RPE) during the precision of force test in either a pushing or pulling direction.

TACTILITY TEST

The intensity of grasp pressure exerted by the participants onto the objects represented a measure of participants' tactile sensitivity. The logic behind this is that grasping force for a certain load will be a function of the loads lifted and the hand conditions. The differences in grasping force for different hand conditions will therefore be directly related to the tactile sensitivity of the corresponding hand conditions. Participants lifted a 100g, a 300g and a 500g load with varying glove conditions. The pressure exerted by digit one (F1) and digit two (F2) were recorded, as muscle activity was evaluated. Perceptual responses were not considered during this test.

Performance responses

Table XXIII: Comparison of participants' digit one (F1) and digit two (F2) force between conditions, for each load lifted (100g, 300g and 500g). Standard deviations indicated in brackets.

		Bare-handed	Nitrile			Neoprene		
			Small	Best fit	Large	Small	Best fit	Large
100g	F1 (N)	1.64 (±1.72)	2.95 (±3.74)	2.40 (±3.35)	2.34 (±2.84)	3.21 (±6.11)	4.34 (±8.07)	8.35 (±13.29)
	F2 (N)	3.06 (±4.82)	3.66 (±7.96)	6.37 (±14.67)	9.00 (±23.70)	4.51 (±14.56)	2.02 (±9.02)	4.62 (±12.92)
300g	F1 (N)	3.41 (±2.53)	4.39 (±5.24)	3.41 (±4.21)	4.27 (±7.10)	3.46 (±5.73)	5.95 (±11.49)	6.57 (±9.64)
	F2 (N)	5.94 (±4.36)	6.89 (±10.33)	6.50 (±14.57)	5.90 (±9.01)	8.68 (±15.06)	5.70 (±13.34)	6.98 (±12.81)
500g	F1 (N)	5.51 (±4.35)	5.83 (±5.84)	3.68 (±5.03)	5.94 (±7.45)	6.22 (±6.90)	7.22 (±11.01)	6.12 (±7.38)
	F2 (N)	13.56 (±14.64)	9.11 (±9.85)	10.17 (±37.90)	9.11 (±13.97)	11.07 (±21.07)	7.26 (±12.80)	14.37 (±21.61)

Table XXIV: Three-factorial analysis of variance of the tactility force for the factors: glove size (small, best fit and large) and material (neoprene and nitrile) and load mass (100g, 300g and 500g).

		Degrees of freedom	F	p
Tactility: F1 (N)	Material	*1*	*5.00266*	*0.031975*
	Sizes	2	0.96450	0.386328
	Mass	*2*	*12.82654*	*0.000019*
	Material*Size	2	1.34614	0.267089
	Material*Mass	2	2.11612	0.128365
	Size*Mass	4	1.47261	0.213910
	Material*Size*Mass	*4*	*3.34677*	*0.011974*
Tactility: F2 (N)	Material	1	0.00817	0.928502
	Sizes	2	0.39719	0.673755
	Mass	*2*	*8.42131*	*0.000540*
	Material*Size	2	0.48836	0.615767
	Material*Mass	2	1.88073	0.160324
	Size*Mass	4	0.82773	0.509698
	Material*Size*Mass	4	0.89819	0.467008

Table XXV: Two-factorial analysis of variance of the tactility force for the factors: condition (barehanded, nitrile best fit, neoprene best fit) and load mass (100g, 300g and 500g).

		Degrees of freedom	F	p
Tactility: F1 (N)	Condition	2	2.23081	0.115247
	Mass	*2*	*17.49734*	*0.000001*
	Condition*Mass	4	1.44089	0.223857
Tactility: F2 (N)	Condition	2	0.43096	0.651647
	Mass	*2*	*6.24295*	*0.003242*
	Condition*Mass	4	1.37275	0.246640

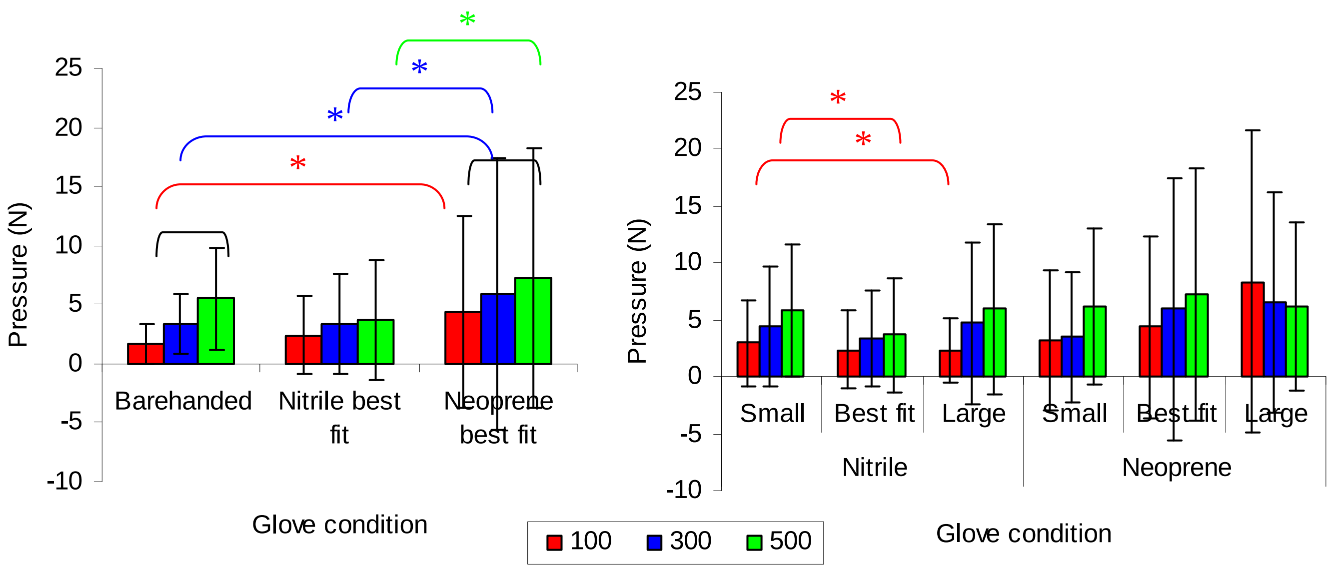

Figure 21: The pressure (N) exerted by digit one (F1) for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

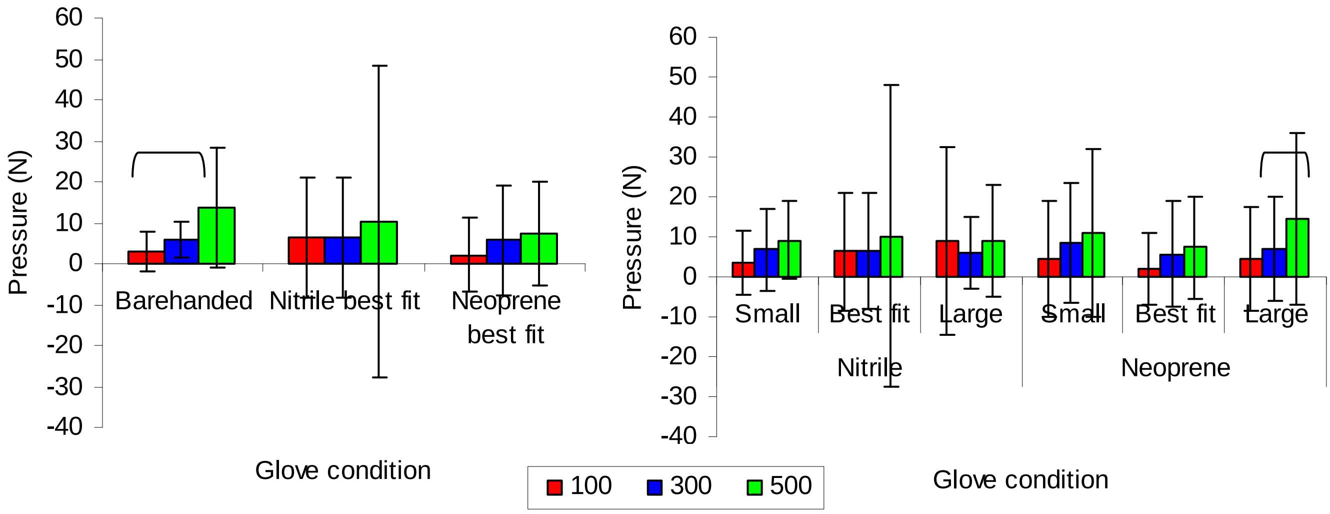

Figure 22: The pressure (N) exerted by digit two (F2) for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

Figure 21 and Figure 22 illustrate the pressure exerted by digit one (F1) and digit two (F2), respectively, whilst lifting each load (100g, 300g and 500g) for each condition.

Significant differences (p<0.05) were calculated for digit one between the 100g and 500g loads for both the barehanded, and the best-fitting neoprene conditions (Figure 21). Further significant differences were established between the barehanded condition and the neoprene condition for the 100g load lifted, and for the 300g load lifted. Significant differences ($p<0.05$) were determined between the nitrile best-fitting and neoprene best-fitting glove conditions for both the 300g and 500g loads lifted (Figure 21).

For the 100g load, the small nitrile glove condition rendered significantly different ($p<0.05$) results to the best-fitting nitrile glove condition and the large nitrile glove condition (Figure 21).

Pressure exerted by digit two did not render any significant differences ($p<0.05$) between materials or sizes, across loads lifted. However significant differences were found between the 100g and 500g loads lifted for the barehanded and the large neoprene glove conditions (Figure 22).

Muscle activity

Muscle activity responses were relativised to the maximal voluntary contractions (MVC) that were performed for each muscle. Therefore, muscle activity results are presented as a percentage of MVC.

Table XXVI: Comparison of participants' muscle activity responses between conditions, for each load lifted (100g, 300g, and 500g). Standard deviations indicated in brackets.

	Muscle	Bare-handed	Nitrile			Neoprene		
			Small	Best fit	Large	Small	Best fit	Large
100g	FDS	1.96 (±0.71)	2.15 (±0.71)	2.10 (±0.70)	2.40 (±1.00)	2.13 (±0.59)	2.19 (±1.01)	2.26 (±0.70)
	FPL	2.51 (±1.16)	2.58 (±1.05)	2.62 (±1.25)	3.28 (±2.11)	2.72 (±1.16)	2.68 (±1.51)	3.03 (±1.44)
	ECU	7.62 (±3.88)	7.66 (±4.36)	7.19 (±4.88)	9.14 (±6.31)	8.04 (±4.78)	7.41 (±5.80)	9.03 (±4.78)
	ECR	3.04 (±3.09)	3.66 (±4.78)	4.03 (±6.05)	4.68 (±4.41)	3.99 (±5.11)	3.79 (±3.96)	4.10 (±4.06)
	FCU	1.42 (±0.68)	1.63 (±0.79)	1.53 (±0.73)	1.59 (±0.82)	1.65 (±0.70)	1.55 (±1.06)	1.64 (±0.74)
	FCR	2.47 (±1.44)	2.66 (±1.63)	2.67 (±1.66)	3.81 (±3.37)	2.97 (±1.73)	2.82 (±2.00)	3.32 (±1.99)
300g	FDS	2.04 (±0.73)	2.19 (±0.86)	2.07 (±0.69)	2.40 (±1.03)	2.00 (±0.69)	2.27 (±1.09)	2.26 (±0.63)
	FPL	2.76 (±1.33)	2.77 (±1.29)	2.78 (±1.39)	2.88 (±1.27)	2.98 (±1.34)	2.81 (±1.55)	2.84 (±1.44)
	ECU	10.24 (±5.11)	8.72 (±4.79)	8.50 (±4.65)	8.61 (±5.74)	8.95 (±5.59)	8.49 (±5.54)	10.97 (±5.66)
	ECR	4.79 (±4.25)	4.62 (±4.48)	5.09 (±5.74)	5.73 (±5.87)	4.97 (±5.47)	4.83 (±5.31)	4.69 (±4.97)
	FCU	1.66 (±0.96)	1.55 (±0.89)	1.61 (±0.69)	1.58 (±0.76)	1.69 (±0.84)	1.61 (±0.85)	1.74 (±0.91)
	FCR	3.13 (±2.09)	3.16 (±1.86)	3.14 (±2.12)	3.48 (±2.33)	3.20 (±2.19)	3.26 (±2.52)	3.40 (±1.86)
500g	FDS	2.60 (±1.31)	2.25 (±0.89)	2.33 (±0.91)	2.35 (±0.75)	2.30 (±0.92)	2.31 (±1.17)	2.44 (±0.81)
	FPL	3.97 (±2.28)	3.24 (±1.65)	3.40 (±1.67)	3.79 (±2.17)	3.40 (±2.07)	3.20 (±1.64)	3.65 (±1.92)
	ECU	14.17 (±6.44)	10.86 (±5.74)	10.53 (±7.22)	12.40 (±7.58)	11.64 (±6.52)	10.48 (±7.55)	13.07 (±6.48)
	ECR	7.60 (±6.47)	5.86 (±7.23)	4.63 (±3.99)	6.71 (±5.33)	7.34 (±8.24)	6.19 (±6.21)	6.57 (±5.63)
	FCU	2.31 (±1.44)	2.03 (±0.99)	1.85 (±0.93)	1.78 (±0.87)	1.87 (±0.93)	1.81 (±0.92)	1.84 (±0.94)
	FCR	4.54 (±3.47)	4.28 (±2.67)	3.83 (±3.14)	5.05 (±4.03)	4.14 (±2.64)	3.76 (±2.61)	5.01 (±3.44)

Table XXVII: Three-factorial analysis of variance of the muscle activity responses during the tactility test for the factors: glove size (small, best fit and large) and material (neoprene and nitrile) and load mass (100g, 300g and 500g). FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

		Degrees of freedom	F	p
FDS	Material	1	0.0330	0.857026
	Sizes	2	2.2832	0.109722
	Mass	*2*	*8.2991*	*0.000596*
	Material*Size	2	0.4316	0.651216
	Material*Mass	2	0.5002	0.608602
	Size*Mass	4	1.1024	0.358064
	Material*Size*Mass	*4*	*3.6842*	*0.007003*
FPL	Material	1	0.0053	0.942180
	Sizes	*2*	*3.1396*	*0.049636*
	Mass	*2*	*26.4894*	*0.000000003*
	Material*Size	2	2.6583	0.077346
	Material*Mass	2	1.0807	0.345121
	Size*Mass	*4*	*2.6413*	*0.036434*
	Material*Size*Mass	4	0.6829	0.604967
ECU	Material	1	2.5152	0.122009
	Sizes	*2*	*3.4534*	*0.037290*
	Mass	*2*	*45.0913*	*0.0000000000003*
	Material*Size	2	0.9433	0.394363
	Material*Mass	2	1.7968	0.173611
	Size*Mass	4	0.5186	0.722176
	Material*Size*Mass	4	2.2163	0.070444
ECR	Material	1	0.51053	0.479787
	Sizes	2	1.97601	0.146502
	Mass	*2*	*36.62318*	*0.000000*
	Material*Size	*2*	*6.18263*	*0.003412*
	Material*Mass	*2*	*7.29250*	*0.001351*
	Size*Mass	4	1.75870	0.140779
	Material*Size*Mass	4	0.83070	0.507849
FCU	Material	1	0.3657	0.549379
	Sizes	2	1.3013	0.278876
	Mass	*2*	*28.9088*	*0.000000001*
	Material*Size	2	1.1926	0.309698
	Material*Mass	*2*	*3.7355*	*0.028892*
	Size*Mass	4	1.9070	0.112769
	Material*Size*Mass	4	1.0542	0.381817
FCR	Material	1	0.0212	0.885188
	Sizes	*2*	*3.5992*	*0.032675*
	Mass	*2*	*29.8151*	*0.000000001*
	Material*Size	2	0.6104	0.546074
	Material*Mass	2	0.3145	0.731196
	Size*Mass	*4*	*3.1217*	*0.017104*
	Material*Size*Mass	4	1.3547	0.253026

Table XXVIII: Two-factorial analysis of variance of the muscle activity responses from the tactility test for the factors: condition (barehanded, nitrile best fit, neoprene best fit) and load mass (100g, 300g and 500g). FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

		Degrees of freedom	F	p
FDS	Condition	2	0.2357	0.790658
	Mass	2	14.3869	0.000006
	Condition*Mass	4	7.2639	0.000025
FPL	Condition	2	0.7969	0.454868
	Mass	2	34.4731	0.000000
	Condition*Mass	4	6.0693	0.000159
ECU	Condition	2	8.7061	0.000430
	Mass	2	40.9353	0.000000000002
	Condition*Mass	4	9.5084	0.000001
ECR	Condition	2	1.82184	0.169534
	Mass	2	19.17404	0.0000002
	Condition*Mass	4	7.74033	0.000012
FCU	Condition	2	1.9432	0.151110
	Mass	2	37.3224	0.00000000001
	Condition*Mass	4	9.7224	0.000001
FCR	Condition	2	0.52389	0.594585
	Mass	2	21.81327	0.00000005
	Condition*Mass	4	6.97451	0.000039

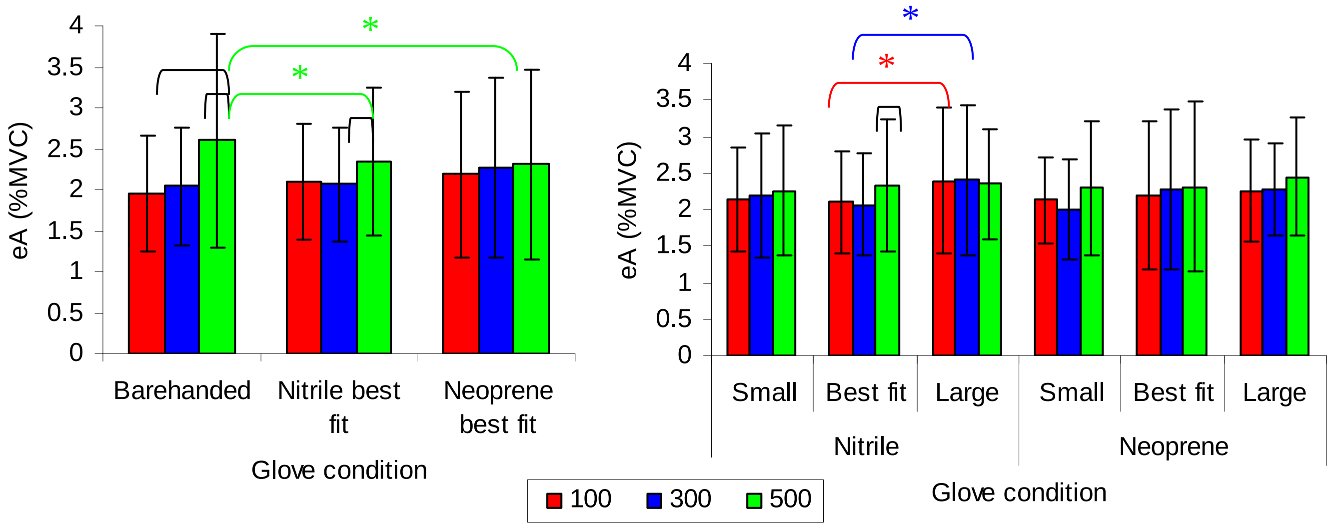

Figure 23: The muscle activity responses of the **Flexor Digitorum Superficialis** for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

Figure 23 illustrates significant differences (p<0.05) between conditions for the Flexor Digitorum Superficialis muscle. It can be seen that significant differences (p<0.05) were calculated for the barehanded condition between the 100g and the 500g loads, and between the 300g and the 500g loads. A further significant difference (p<0.05) was determined between the 300g and the 500g loads for the nitrile best-fitting glove condition. Significant differences (p<0.05) were also established across loads, between conditions. The barehanded condition responses were significantly different to both the nitrile best-fitting glove and the neoprene best-fitting glove responses for the 500g load lifted. Significant differences (p<0.05) were also found between the best-fitting nitrile glove and large nitrile glove conditions for both 100g and the 300g loads lifted.

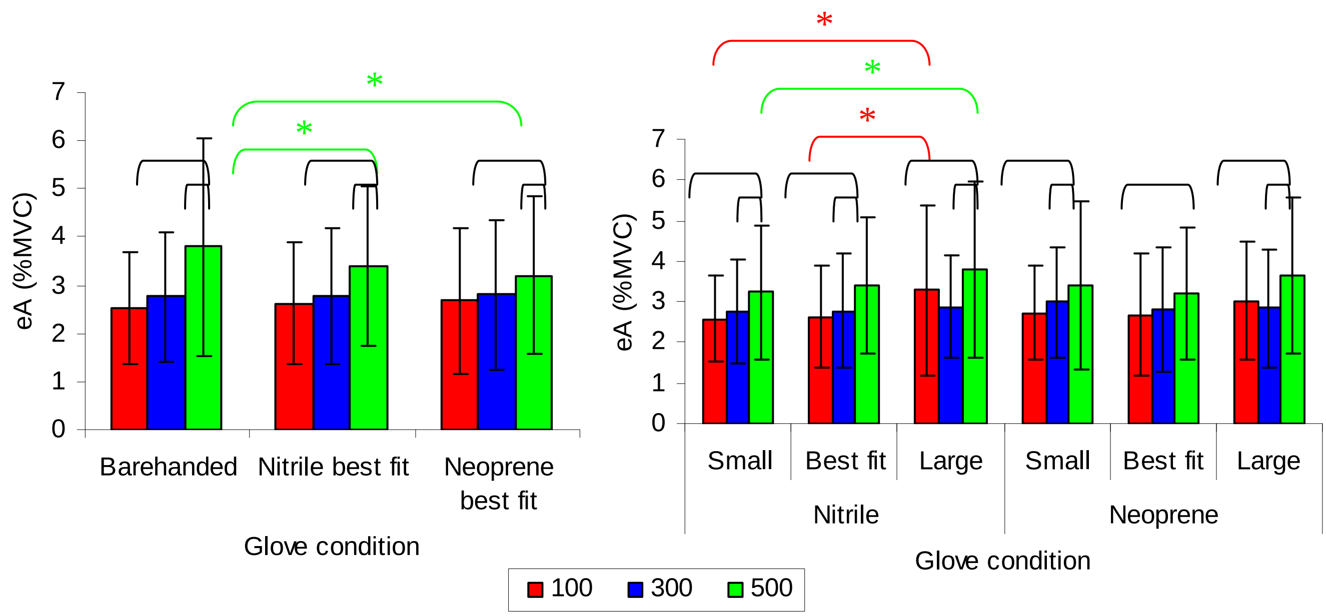

Figure 24: The muscle activity responses of the **Flexor Pollicus Longus** for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

As seen in Figure 24 significant differences (p<0.05) were calculated between the 100g and the 500g, and the 300g and the 500g loads lifted for all conditions for the Flexor Pollicus Longus muscle. Significant differences (p<0.05) were also found between conditions across loads. These were determined between the barehanded condition and the nitrile best-fitting glove, and the barehanded condition and the neoprene best-fitting glove for the 500g load lifted; between the nitrile small glove condition and the nitrile large glove condition for the 500g load lifted; and between the nitrile best-fitting and the nitrile large glove conditions, and the nitrile small glove condition and the nitrile large glove condition for the 100g load lifted.

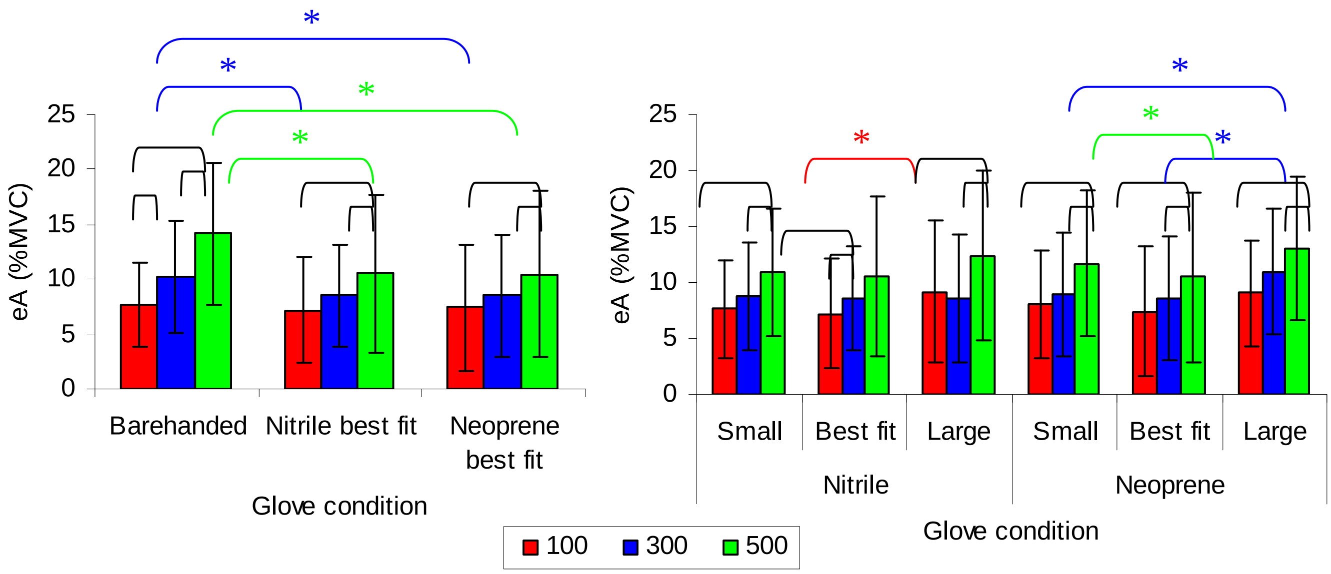

Figure 25: The muscle activity responses of the **Extensor Carpi Ulnaris** for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

The Extensor Carpi Ulnaris muscle responses rendered significant differences (p<0.05) between the 100g and the 500g loads lifted and the 300g and the 500g loads lifted for each condition (Figure 25). A significant difference was also found between the 100g and the 300g loads for the barehanded conditions.

Figure 25 also illustrates significant differences (p<0.05) between conditions across loads. It can be seen that there are significant differences (p<0.05) between the barehanded condition and the nitrile best-fitting glove condition and the barehanded condition and the neoprene best-fitting glove condition for the 100g and the 300g loads lifted. Significant differences (p<0.05) were also established between the nitrile best-fitting and the nitrile large glove conditions for the 100g load; and between the neoprene small and the neoprene large conditions, and between the neoprene best-fitting and the neoprene large conditions for the 300g load. Lastly, a significant difference (p<0.05) was found for the 300g load lifted between neoprene small glove condition and neoprene best-fitting glove condition.

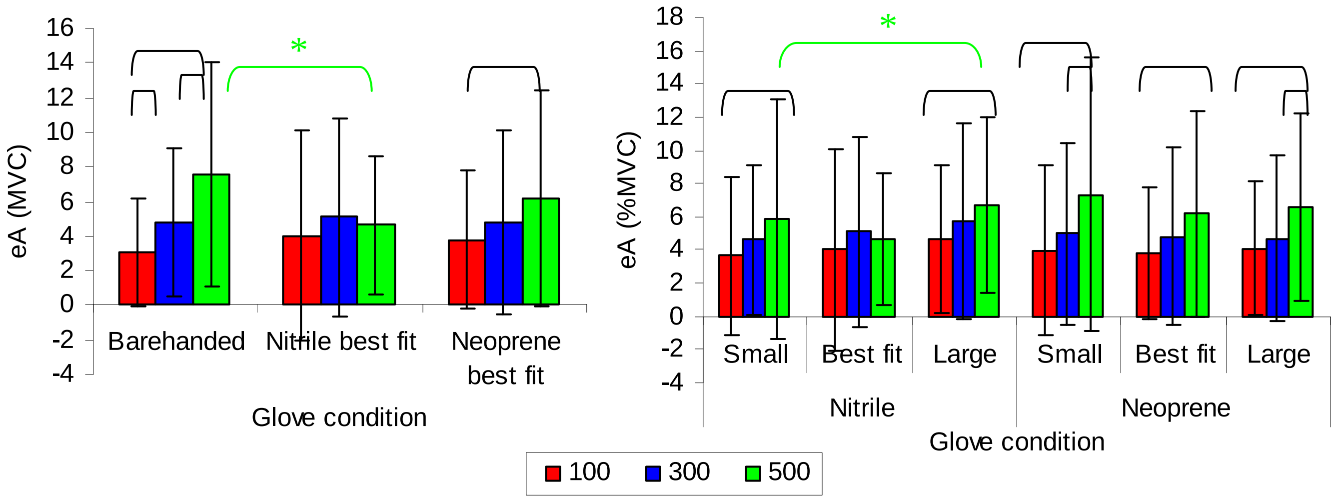

Figure 26: The muscle activity responses of the **Extensor Carpi Radialis** for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

Figure 26 shows significant differences (p<0.05) between conditions and loads for the Extensor Carpi Radialis muscle responses. Significant differences (p<0.05) between loads lifted were found between the 100g and 500g loads for the barehanded, nitrile small, nitrile large and all neoprene glove conditions. Significant differences (p<0.05) were calculated between the 100g and the 300g loads, and between the 300g and the 500g loads for the barehanded condition, between the 300g and the 500g loads for the neoprene small glove and neoprene large glove conditions. Significant differences (p<0.05) between conditions of the same load include the barehanded condition and the nitrile best-fitting glove condition at 500g; and between the nitrile small and the nitrile large glove conditions at 500g.

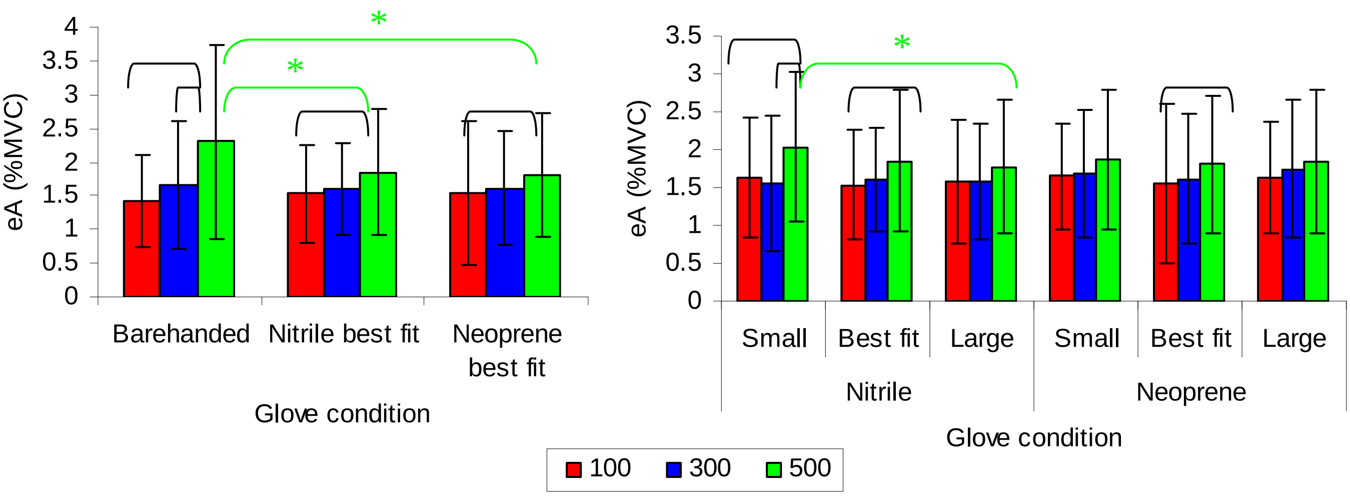

Figure 27: The muscle activity responses of the **Flexor Carpi Ulnaris** for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

The Flexor Carpi Ulnaris muscle activity responses for each condition during the tactility test can be seen in Figure 27. Significant differences (p<0.05) were found between the 100g and 500g loads for the barehanded, nitrile small, nitrile best fit and neoprene best fit conditions. Further significant differences (p<0.05) between loads include between the 300g and the 500g loads for the barehanded condition and the nitrile small glove condition. Significant differences (p<0.05) were found between conditions across the same mass. These were between barehanded and nitrile best-fitting and between barehanded and neoprene best-fitting and between nitrile small and nitrile large for the 500g load.

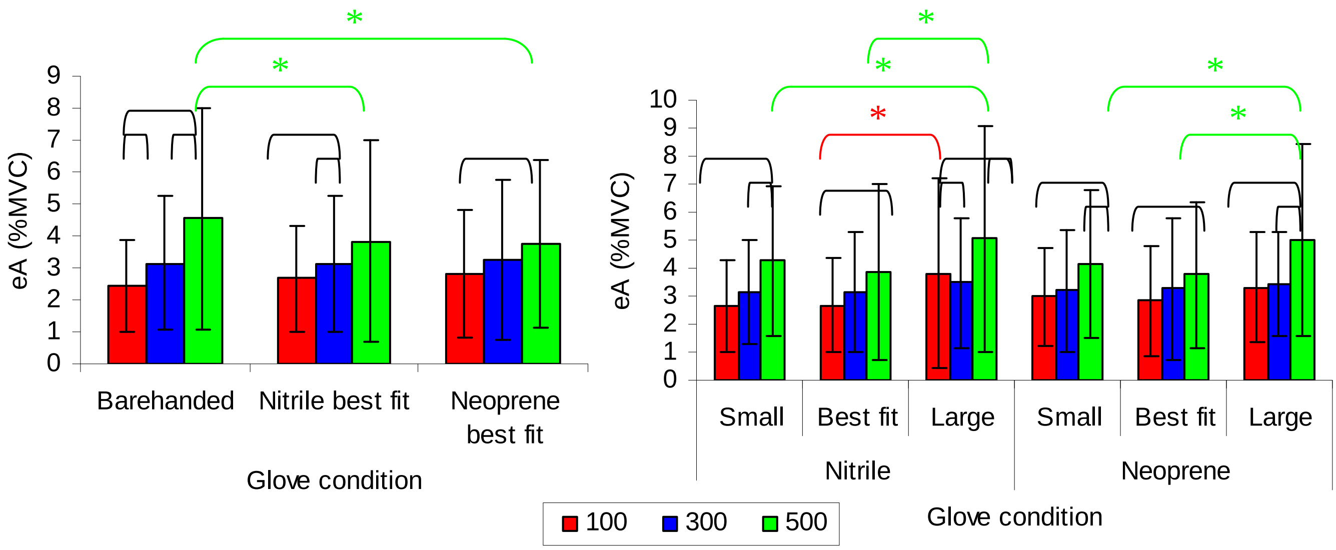

Figure 28: The muscle activity responses of the **Flexor Carpi Radialis** for each load (100g, 300g and 500g) during the tactility test comparing conditions (left) and the materials and sizes (right). * denotes a statistically significant difference, p<0.05).

Figure 28 indicated muscle activity responses for the Flexor Carpi Radialis muscle during the tactility test. Significant differences (p<0.05) were found between the 100g and 500g loads for all conditions. Significant differences were found between the 300g and 500g loads for the barehanded condition, all nitrile glove conditions, and the neoprene small and neoprene large glove conditions. Lastly, significant differences (p<0.05) were found between the 300g and 500g loads for the barehanded condition and the large nitrile glove condition. Significant differences (p<0.05) were also found between conditions across the same load, including between the barehanded condition and the nitrile best fit glove condition, and between the barehanded condition and the neoprene best fit glove condition for the 500g load. Further significant differences (p<0.05) for the 500g load include those between the small and large and between the best-fitting and large conditions for both the nitrile and neoprene materials. Lastly, a significant difference (p<0.05) was calculated between the nitrile best-fitting and the nitrile large glove conditions for the 100g load lifted.

SPEED AND ACCURACY TEST

Performance responses recorded during this test included participants' movement time and deviation from the intended target. Muscle activity and perceptual responses were not evaluated during this test.

Performance responses

Movement time directly influences task completion time and productivity, and is therefore an indicator of efficiency (Gunasekaran *et al.*, 1994). Effective task completion is a combination of efficiency and the quality of the output, therefore performance in this test integrated both movement time, and the deviation from the centre of the target.

Accuracy can be defined as the ability consistently to adhere to predefined tolerance limits (Schmidt and Lee, 2005; Guastello, 2006), which can be quantified by analysing deviations from the target. Deviations were measured from the centre of the target.

Table XXIX: Participants' mean reaction time (s) and deviation from the target (mm) for each condition. Standard deviations indicated in brackets.

	Bare-handed	Nitrile			Neoprene		
		Small	Best fit	Large	Small	Best fit	Large
Reaction time (s)	0.47 (±0.05)	0.47 (±0.05)	0.47 (±0.05)	0.49 (±0.06)	0.49 (±0.06)	0.49 (±0.04)	0.51 (±0.06)
Target deviation (mm)	7.70 (±1.88)	7.57 (±1.85)	7.67 (±1.88)	8.20 (±2.16)	7.89 (±1.86)	8.58 (±2.08)	8.06 (±1.97)

Table XXX: Two-factorial analysis of variance of the speed and accuracy responses for the factors: glove size (small, best fit and large) and material (neoprene and nitrile).

		Degrees of freedom	F	p
Speed and accuracy: target deviation (mm)	Material	*1*	*5.2021*	*0.028946*
	Size	2	2.8142	0.066951
	Material*Size	*2*	*4.1195*	*0.020478*

Table XXXI: One-factorial analysis of variance of the speed and accuracy responses for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition)

		Degrees of freedom	F	p
Speed and accuracy: reaction time (s)	Condition	*2*	*4.257*	*0.018123*
Speed and accuracy: target deviation (mm)	Condition	*2*	*9.4671*	*0.000236*

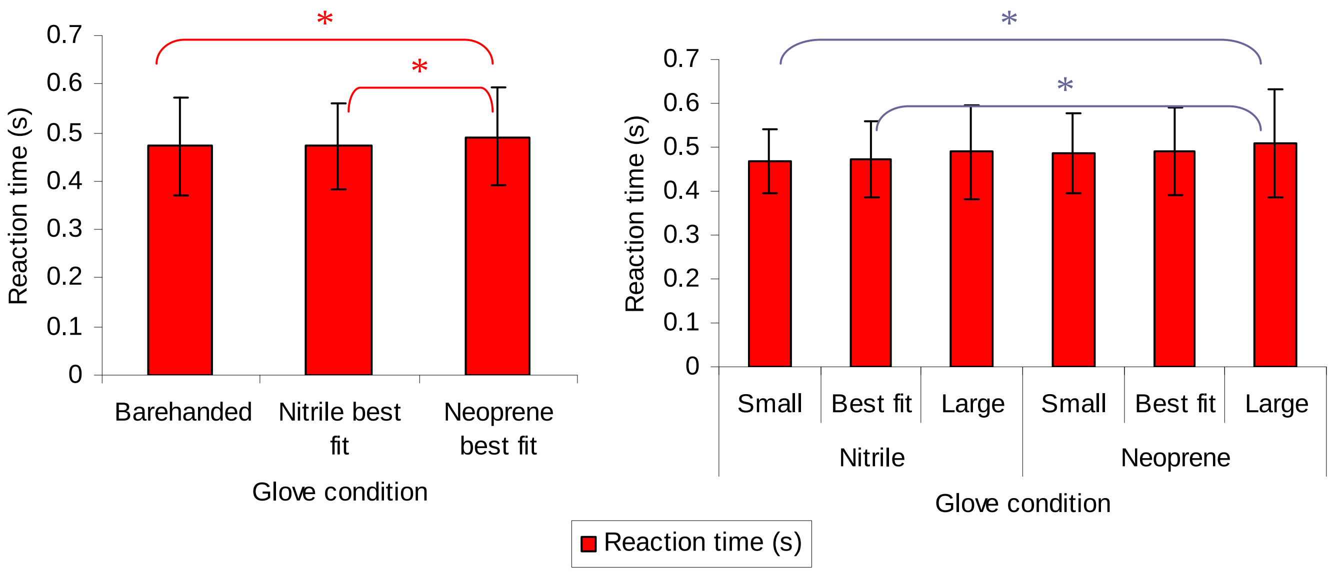

Figure 29: Comparison of the reaction time (s) responses between conditions (left) and materials and sizes (right) during the speed and accuracy test (* denotes a statistically significant difference, p<0.05).

Figure 29 illustrates significant differences (p<0.05) between the barehanded condition and the best-fitting neoprene glove condition; and the best-fitting nitrile glove condition and the best-fitting neoprene glove condition, for participants' reaction time responses during the speed and accuracy test. The nitrile best-fitting glove elicited the best reaction time responses.

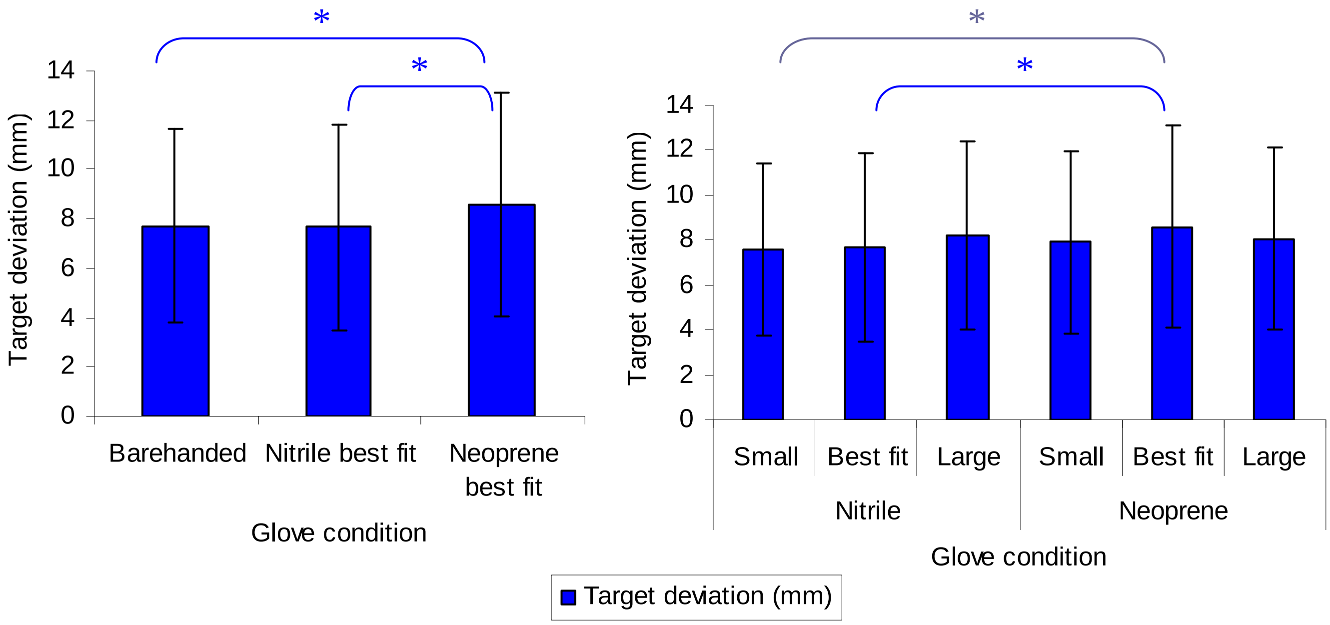

Figure 30: Comparison of the target deviation (mm) between conditions (left) and materials and sizes (right) during the speed and accuracy test (* denotes a statistically significant difference, $p<0.05$).

Significant differences ($p<0.05$) were calculated between conditions for participants' target deviation during the speed and accuracy test. Once again, the nitrile best-fitting glove elicited the best responses, as compared with the barehanded condition, and the neoprene best-fitting glove condition (Figure 30).

DEXTERITY TEST

Muscle activity and perceptual responses were not considered during this test.

Performance responses

The use of protective gloves has been recommended in a variety of working environments to protect workers from various hazards. However, workers often choose to work bare-handed as wearing gloves has been found to impede dexterity performance (Berger *et al.*, 2008).

Dexterity tests are used to assess performance decrements due to gloves. The Minnesota Dexterity Test quantifies dexterity by means of a time score in seconds.

Table XXXII: Participants' dexterity time scores (s) for each condition. Standard deviations indicated in brackets.

Bare-handed	Nitrile			Neoprene		
	Small	Best fit	Large	Small	Best fit	Large
76 (±8.22)	90 (±11.22)	90 (±13.15)	99 (±15.20)	93 (±14.40)	93 (±14.86)	103 (±17.22)

Table XXXIII: Two-factorial analysis of variance of participants' dexterity time for the factors: glove size (small, best fit and large) and material (neoprene and nitrile).

		Degrees of freedom	F	P
Dexterity (s)	Material	*1*	*6.763*	*0.013676*
	Size	2	18.902	0.000000
	Material*Size	*2*	*0.161*	*0.852011*

Table XXXIV: One-factorial analysis of variance of dexterity time for the barehanded, nitrile best-fitting and neoprene best-fitting conditions (Condition).

		Degrees of freedom	F	p
Dexterity (s)	Condition	*2*	*42.195*	*0.000000000001*

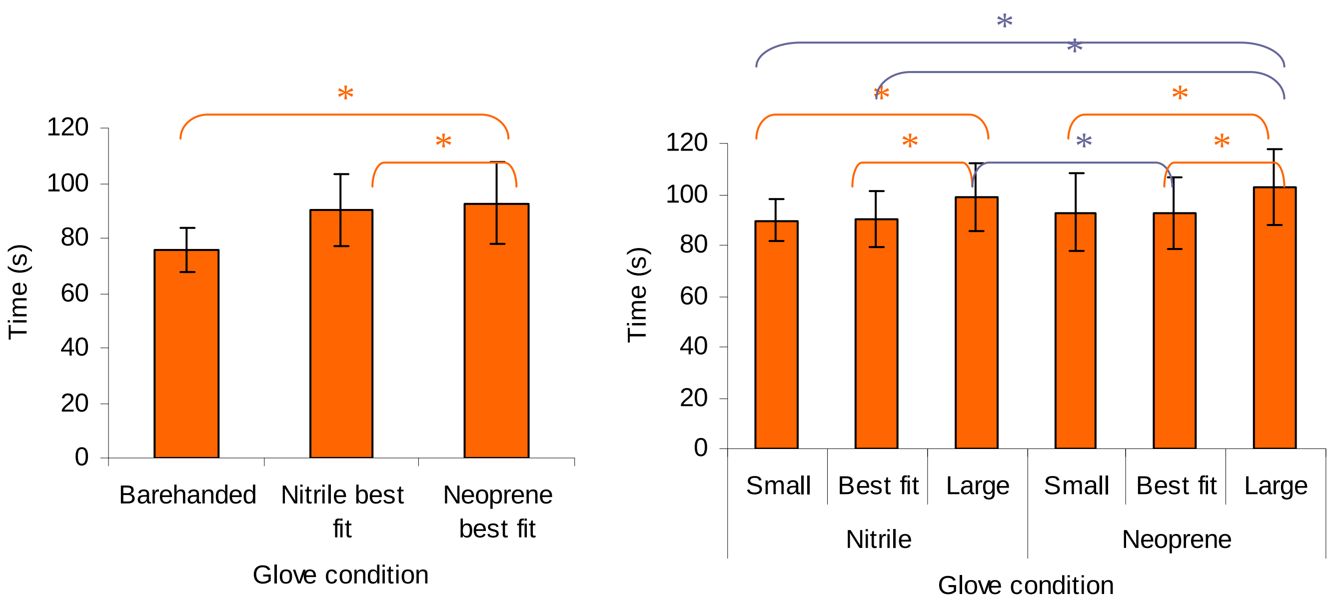

Figure 31: Comparison of the dexterity time (s) between conditions (left) and materials and sizes (right) (* denotes a statistically significant difference, p<0.05).

Significant differences ($p<0.05$) were found between the nitrile best fit condition and the barehanded condition, and the nitrile best fit condition and the neoprene best fit condition, as seen in Figure 31. Furthermore, significant differences ($p<0.05$) were calculated between the large glove condition and the best-fitting glove condition, and between the large glove condition and the small glove conditions, for both the nitrile and neoprene glove materials.

OVERVIEW

The overview is divided such that performance responses (components of task performance) are presented, followed by human responses (muscle activity). Tactility test results have been presented in separate tables.

Performance responses

Table XXXV, Table XXXVI and Table XXXVII indicate significant differences ($p<0.05$) between glove conditions regarding components of task performance. No significant differences ($p<0.05$) were calculated between glove sizes, or between the barehanded, and best-fitting conditions, for force production, either maximal force or precision of force (Table XXXV and Table XXXVII). The only test which rendered significant differences ($p<0.05$) between the neoprene and nitrile material of the same glove size was the speed and accuracy test, as can be seen in Table XXXVI.

Table XXXV: A comparison of the gloves' sizes within each material, for each performance test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05). Tests which generated no significant differences (p<0.05) whatsoever have been omitted.

		Nitrile		Neoprene	
		Best fit	Large	Best fit	Large
Dexterity (s)	Small	n.s.	0.000590	n.s	0.000256
	Best fit		0.001259		0.000186
Reaction time (s)	Small	n.s.	n.s.	n.s.	n.s.
	Best fit		n.s.		n.s.
Target deviation (mm)	Small	n.s.	n.s.	n.s.	n.s.
	Best fit		n.s.		n.s.
Peak torque ext. rotation (Nm)	Small	n.s.	n.s.	n.s.	n.s.
	Best fit		n.s.		n.s.
Peak torque int. rotation (Nm)	Small	n.s.	n.s.	0.018712	n.s.
	Best fit		n.s.		n.s.
Average power ext. rotation (J)	Small	n.s.	n.s.	n.s.	n.s.
	Best fit		n.s.		n.s.
Average power int. rotation (J)	Small	0.037498	n.s.	n.s.	n.s.
	Best fit		n.s.		n.s.

As seen in Table XXXV the dexterity results show significant differences (p<0.05) between the large glove, and the best-fitting glove and between the large glove and the small glove for both materials.

During the maximum torque test (internal rotation), participants exerted a significantly greater (p<0.05) peak torque with the neoprene best-fitting glove than with the small glove size. The same was found for average power (internal rotation) with the nitrile glove.

Table XXXVI: A comparison of glove materials across each size, for each of the performance parameters during each performance test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05). Tests which generated no significant differences (p<0.05) whatsoever have been omitted.

			Neoprene		
			Small	Best fit	Large
Target deviation (mm)	Nitrile	Small	n.s.	n.s.	n.s.
		Best fit	n.s.	0.009294	n.s.
		Large	n.s.	n.s.	n.s.

It can be seen (Table XXXVI) that only a single significant difference (p<0.05) was found between glove materials of the same size, being between the neoprene and nitrile best-fitting gloves, for participants' deviation from the target during the speed and accuracy test.

Table XXXVII: A comparison of the barehanded condition with the best-fitting condition of each material, for each performance test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05). Tests which generated no significant differences (p<0.05) whatsoever have been omitted.

		Best fit nitrile	Best fit neoprene
Dexterity (s)	Barehanded	0.000112	0.000112
	Best fit nitrile		n.s.
Reaction time (s)	Barehanded	n.s.	0.041275
	Best fit nitrile		0.032469
Target deviation (mm)	Barehanded	n.s.	0.001321
	Best fit nitrile		0.000916
Peak torque ext. rotation (Nm)	Barehanded	0.000117	0.000117
	Best fit nitrile		n.s.
Peak torque int. rotation (Nm)	Barehanded	0.000117	0.000117
	Best fit nitrile		n.s.
Total work ext. rotation (Nm)	Barehanded	0.000117	0.000117
	Best fit nitrile		n.s.
Total work int. rotation (Nm)	Barehanded	n.s.	n.s.
	Best fit nitrile		n.s.
Average power ext. rotation (J)	Barehanded	0.000117	0.000117
	Best fit nitrile		n.s.
Average power int. rotation (J)	Barehanded	0.000117	0.000117
	Best fit nitrile		n.s.

In Table XXXVII it can be seen that during the dexterity test, there was a significant difference (p<0.05) in the dexterity score between the barehanded condition, and each of the best fitted glove conditions.

For the speed and accuracy test, participants' reaction time when donning the best-fitting neoprene glove was significantly different (p<0.05) to that of the barehanded condition or the best-fitting nitrile glove. The same was found for target deviation.

During both internal and external rotation in the torque test, the barehanded condition generated significantly different (p<0.05) peak torque to the best-fitting nitrile and best-fitting neoprene gloves. The same was found for the total work (external rotation), and the average power (external and internal rotation) results.

Tactility test results have been presented in separate tables (Table XXVIII, Table XXIX, Table XXX and Table XXXI). These results have been divided into a comparison of conditions when the same load was lifted; and a comparison of loads within each condition.

Table XXXVIII: A comparison of the pressure (N) exerted between the glove conditions across each mass during the tactility test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05).

			Neoprene					
			Best fit			Large		
		Mass	100	300	500	100	300	500
F1 (N)	Small	100	n.s.	n.s.	n.s.	0.000382	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				0.027033	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.

No significant differences (p<0.05) were established for the nitrile glove material conditions, or for the neoprene glove conditions for digit 2 (F1) (Table XXXVIII).

Table XXXIX: A comparison of the barehanded condition with the best-fitting neoprene and nitrile condition, across each mass, for digit pressure (N) during tactility test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05).

			Best fit nitrile			Best fit neoprene		
		Mass	100	300	500	100	300	500
F1 (N)	Barehanded	100	n.s.	n.s.	n.s.	0.018549	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	0.036130	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Significant differences (p<0.05) were only established between the barehanded, best-fitting nitrile and best-fitting neoprene glove conditions for digit 1 (F1) across loads lifted (Table XXXIX).

Table XL: A comparison of the pressure (N) exerted between the glove masses in each condition during the tactility test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$).

			Neoprene					
			Small		Best fit		Large	
		Mass	100	300	100	300	100	300
F2 (N)	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.030079	n.s.

As seen in Table XL, significant differences ($p<0.05$) between loads lifted were only found for digit 2 (F2) for the neoprene glove material conditions.

Table XLI: A comparison of the masses across the barehanded condition, the best-fitting neoprene and the best-fitting nitrile conditions for pressure responses (N) during tactility test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$).

			Barehanded		Best fit nitrile		Best fit neoprene	
			100	300	100	300	100	300
F1	Barehanded	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000044	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.008397	n.s.
F2	Barehanded	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000795	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Human responses

Table XLII, Table XLIII and Table XLIV compare glove sizes, and materials indicating significant differences ($p<0.05$) for muscle activity responses. With regards to Table XLIII, tests which were omitted due to complete lack of significant differences ($p<0.05$) include the maximum force task. There were no significant differences ($p<0.05$) found between any of the glove sizes for any of the muscles during either the maximum pushing, or pulling task. Furthermore, during the precision of force pulling test, there were no significant differences ($p<0.05$) calculated for participants' deviation from the force trend results.

In Table XLIII it can be seen that only the maximum pulling task elicited any responses with significant differences ($p<0.05$) between the glove sizes. Therefore, there were no significant differences between the neoprene and the nitrile gloves across any of the sizes, for any muscle, for the maximum pushing, maximum torque, or precision of force tasks.

The only test which elicited significant differences ($p<0.05$) between glove materials of the same size was the maximum pulling force test. As seen in Table XLIII, differences were measured for the Extensor Carpi Radialis muscle between the neoprene and nitrile best-fitting gloves.

Table XLIV shows that no significant differences ($p<0.05$) were recorded during the maximum pulling force task. For the precision of force test, significant differences ($p<0.05$) were only indicated for deviation from the force trend, in a pushing direction. No significant differences ($p<0.05$) were found in a pulling direction, or for the force trend in a pushing direction.

Table XLII: A comparison of the gloves' sizes within each material, for each of the human responses during each performance test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$). Tests which generated no significant differences ($p<0.05$) whatsoever have been omitted.

			Nitrile		Neoprene	
	Muscle	Glove size	Best fit	Large	Best fit	Large
Maximum torque (%MVC)	FDS	Small	n.s.	n.s.	n.s.	0.004987
		Best fit		n.s.		n.s.
	FPL	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	ECU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	ECR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
Force trend, pulling (%MVC)	FDS	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FPL	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		0.022775		n.s.
	ECU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	ECR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCR	Small	n.s.	n.s.	n.s.	n.s
		Best fit		n.s.		n.s.
Force trend, pushing (%MVC)	FDS	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FPL	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	ECU	Small	n.s.	n.s	n.s.	0.037336
		Best fit		n.s		n.s
	ECR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
Deviation from trend, pushing (%MVC)	FDS	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		0.034573		n.s.
	FPL	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	ECU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	ECR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.
	FCU	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		0.007486
	FCR	Small	n.s.	n.s.	n.s.	n.s.
		Best fit		n.s.		n.s.

In Table XLII, a significant difference (p<0.05) can be seen during the maximum torque task, for the Flexor Digitorum Superficialis muscle, between the neoprene small and large gloves. A significant difference (p<0.05) was calculated between the force trend of the nitrile best-fitting and the nitrile large gloves, for the precision of force pulling test, for the Flexor Pollicus Longus. A further significant difference was recorded during the precision of force test. This was found between the force trend of the neoprene small and the neoprene large gloves for the Extensor Carpi Ulnaris muscle during the pushing task.

Table XLIII: A comparison of glove materials across each size, for each of the human responses during each performance test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05). Tests which generated no significant differences (p<0.05) whatsoever have been omitted. FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

				Neoprene		
	Muscle	Glove		Small	Best fit	Large
Maximum pulling force (%MVC)	FDS	Nitrile	Small	n.s.	n.s.	n.s.
			Best fit	n.s.	n.s.	n.s.
			Large	n.s.	n.s.	n.s.
	FPL	Nitrile	Small	n.s.	n.s.	n.s.
			Best fit	n.s.	n.s.	n.s.
			Large	n.s.	n.s.	n.s.
	ECU	Nitrile	Small	n.s.	n.s.	n.s.
			Best fit	n.s.	n.s.	n.s.
			Large	n.s.	n.s.	n.s.
	ECR	Nitrile	Small	n.s.	n.s.	n.s.
			Best fit	n.s.	n.s.	n.s.
			Large	n.s.	n.s.	0.006701
	FCU	Nitrile	Small	n.s.	n.s.	n.s.
			Best fit	n.s.	n.s.	n.s.
			Large	n.s.	n.s.	n.s.
	FCR	Nitrile	Small	n.s.	n.s.	n.s.
			Best fit	n.s.	0.022943	n.s.
			Large	n.s.	n.s.	n.s.

The only test which elicited significant differences (p<0.05) between glove materials of the same size was the maximum pulling force test. As seen in Table XLIII, differences were measured for the Extensor Carpi Radialis muscle between the neoprene and nitrile large gloves; and for the Flexor Carpi Ulnaris between the neoprene and nitrile best-fitting gloves.

Table XLIV: A comparison of the barehanded condition with the best-fitting neoprene and nitrile condition, for each of the human responses during each performance test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05). Tests which generated no significant differences (p<0.05) whatsoever have been omitted.

		Glove condition	Best fit nitrile	Best fit neoprene
Maximum torque (%MVC)	FDS	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FPL	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECU	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECR	Barehanded	0.026372	0.005504
		Best fit nitrile		n.s.
	FCU	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FCR	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
Maximum pulling force (%MVC)	FDS	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FPL	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECU	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECR	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FCU	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FCR	Barehanded	n.s.	n.s.
		Best fit nitrile		0.012513
Maximum pushing force (%MVC)	FDS	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FPL	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECU	Barehanded	0.016628	n.s.
		Best fit nitrile		n.s.
	ECR	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FCU	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FCR	Barehanded	n.s.	0.000112
		Best fit nitrile		0.000112
30% pushing force Deviation from trend	FDS	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FPL	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECU	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	ECR	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.
	FCU	Barehanded	0.000112	n.s.
		Best fit nitrile		0.000112
	FCR	Barehanded	n.s.	n.s.
		Best fit nitrile		n.s.

Table XLIV illustrates a significant difference between the barehanded condition and the best fit nitrile glove; and the barehanded condition and the best fit neoprene glove for the Extensor Carpi Radialis during the maximum torque task. For the maximum pulling force test, a significant difference ($p<0.05$) was determined for the Flexor Carpi Ulnaris between the best fit nitrile and best fit neoprene gloves. The maximum pushing force test also produced significant differences ($p<0.05$). These were found between the barehanded condition and the nitrile best-fitting glove for the Extensor Carpi Ulnaris; and between the barehanded condition and the best-fitting nitrile glove, and the barehanded condition and the best-fitting neoprene glove for the Flexor Carpi Radialis. For the precision of force test, only the pushing task produced a significant difference ($p<0.05$), for the deviation from the force trend calculation. A significant difference ($p<0.05$) was recorded between the best fit nitrile glove and the best fit neoprene glove; and between the barehanded condition and the best fit nitrile glove for the Flexor Carpi Ulnaris.

Tactility test results have been presented in separate tables (Table XLV, Table XLVI, Table XLVII, Table XLVIII, Table XLIX and Table L). These results have been divided into a comparison of conditions when the same load was lifted; and a comparison of loads within each condition.

Table XLV: A comparison of the muscle activity (mV) elicited between the nitrile glove conditions across each mass during the tactility test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$).

			Nitrile					
			Best fit			Large		
		Mass	100	300	500	100	300	500
FDS	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				0.007914	n.s.	n.s.
		300				n.s.	0.001038	n.s.
		500				n.s.	n.s.	n.s.
FPL	Small	100	n.s.	n.s.	n.s.	0.000036	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	0.000410
	Best fit	100				0.000039	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
ECU	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				0.038550	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
ECR	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	0.000054
FCU	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	0.038989
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
FCR	Small	100	n.s.	n.s.	n.s.	0.000041	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	0.025514
	Best fit	100				0.000043	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	0.000037

Table XLVI: A comparison of the muscle activity (mV) elicited between the neoprene glove conditions across each mass during the tactility test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$).

			Neoprene					
			Best fit			Large		
		Mass	100	300	500	100	300	500
FDS	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
FPL	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
ECU	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	0.000862
		500				n.s.	0.000342	n.s.
ECR	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
FCU	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	n.s.
FCR	Small	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	0.004311
	Best fit	100				n.s.	n.s.	n.s.
		300				n.s.	n.s.	n.s.
		500				n.s.	n.s.	0.000036

As illustrated in Table XLV and Table XLVI, glove conditions were compared across each mass, Nitrile glove responses, and neoprene glove responses can be seen in Table XLV and Table XLVI respectively. For the nitrile glove material, there was a significant difference ($p<0.05$) between the muscle activity of the Flexor Digitorum Superficialis muscle when donning the large glove, and the best-fitting glove during the 100g and the 300g conditions.

With regard to muscle activity of the Flexor Pollicus Longus, significant differences ($p<0.05$) were calculated between the small glove and the large glove; and the best-fitting glove and the large glove when 100g was lifted. Furthermore, there was a significant difference established for the 500g mass between the large and small glove conditions.

A single significant difference ($p<0.05$) was found for both the Extensor Carpi Ulnaris and Extensor Carpi Radialis muscle responses. Significant differences ($p<0.05$) were calculated between the muscle activity elicited during the large glove condition, and the best-fitting glove conditions when the 100g, and 500g loads were lifted, for the Extensor Carpi Ulnaris and Extensor Carpi Radialis muscles respectively.

Significant differences ($p<0.05$) were established for the Flexor Carpi Radialis muscle between the large and small, and the large and best-fitting glove conditions during the 100g and 500g loads.

Fewer significant differences ($p<0.05$) were attained for the neoprene glove material, as shown in Table XLVI. Significant differences ($p<0.05$) were calculated for the Extensor Carpi Ulnaris muscle activity responses between the large and best-fitting glove conditions for the 300g and 500g loads. Further significant differences ($p<0.05$) were established for the Flexor Carpi Radialis muscle between the large glove and the small glove conditions; and the large glove and the best-fitting glove conditions for the 500g load lifted.

Table XLVII: A comparison of the barehanded condition with the best-fitting neoprene and nitrile condition, across each mass, for muscle activity responses during tactility test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05).

			Best fit nitrile			Best fit neoprene		
		Mass	100	300	500	100	300	500
FDS	Barehanded	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	0.034432	n.s.	n.s.	0.011192
FPL	Barehanded	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	0.029811	n.s.	n.s.	0.000032
ECU	Barehanded	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	0.003302	n.s.	n.s.	0.002839	n.s.
		500	n.s.	n.s.	0.000010	n.s.	n.s.	0.000010
ECR	Barehanded	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	0.000011	n.s.	n.s.	n.s.
FCU	Barehanded	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	0.000011	n.s.	n.s.	0.000010
FCR	Barehanded	100	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		300	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	0.001076	n.s.	n.s.	0.000199

Table XLVII shows significant differences (p<0.05) between the barehanded condition and the best-fitting conditions of both the nitrile and neoprene materials. Differences were calculated for each muscle. For the Flexor Digitorum Superficialis muscle significant differences (p<0.05) were determined between the barehanded condition and both best-fitting conditions for the 500g load. The same was found for the Flexor Pollicus Longus, Extensor Carpi Ulnaris, Flexor Carpi Ulnaris and Flexor Carpi Radials muscles. Further significant differences (p<0.05) were found between the barehanded condition and both best-fitting conditions for Extensor Carpi Ulnaris muscle activity responses during the 300g load. For the Extensor Carpi Radialis muscle a significant difference (p<0.05) was only found between the barehanded condition and the best fit nitrile glove condition during the 500g load.

Table XLVIII: A comparison of the muscle activity elicited (mV) between the nitrile glove masses in each condition during the tactility test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$).

			Nitrile					
			Small		Best fit		Large	
		Mass	100	300	100	300	100	300
FDS	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000039	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	0.039578	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FPL	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000039	0.009330	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.000036	0.000055	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.001937	0.000036
ECU	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000036	0.011562	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.000036	0.024727	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000036	0.000036
ECR	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000069	n.s.
FCU	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000038	0.000036	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.000777	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FCR	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000036	0.000049	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.000040	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000036	0.000036

Table XLIX: A comparison of the muscle activity (mV) elicited for the neoprene glove masses in each condition during the tactility test. Significant differences ($p<0.05$) are indicated by p values. n.s. specifies no significant differences ($p<0.05$).

			Neoprene					
			Small		Best fit		Large	
		Mass	100	300	100	300	100	300
FDS	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FPL	Small	300	0.041594		n.s.	n.s.	n.s.	n.s.
		500	0.000037	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.001449	n.s.	0.00006	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	0.000036
ECU	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000036	0.000155	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.000039	0.031868	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	0.043964	
		500	n.s.	n.s.	n.s.	n.s.	0.000036	n.s.
ECR	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000036	0.000036	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.000036	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000036	0.000304
FCU	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.026378	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FCR	Small	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000040	0.001296	n.s.	n.s.	n.s.	n.s.
	Best fit	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.001162	n.s.	n.s.	n.s.
	Large	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000036	0.000036

Table XLVIII and Table XLIX compare muscle activity responses compare muscle activity responses between loads (100g, 300g and 500g) within each condition. For the nitrile glove material, as seen in Table XLVIII, a significant difference ($p<0.05$) was determined between the 100g and 300g loads during the small glove condition for the Flexor Digitorum Superficialis muscle activity responses. The Flexor Pollicus Longus and Extensor Carpi Ulnaris muscle activity responses elicited significant differences ($p<0.05$) between the small, best-fitting and large glove conditions' 100g and 500g loads, and 300g and 500g loads.

A single significant difference ($p<0.05$) was determined for the Extensor Carpi Radialis muscle activity. This was found between the 100g and 500g loads for large glove condition. The Flexor Carpi Ulnaris muscle activity responses resulted in significant differences ($p<0.05$) between the 100g and 500g; and the 300g and 500g loads of the small glove condition. Furthermore, a significant difference ($p<0.05$) was calculated between the 300g and 500g loads of the best-fitting glove condition. The Flexor Carpi Radialis muscle activity responses brought about significant differences ($p<0.05$) between masses in all 3 glove size conditions. Significant differences ($p<0.05$) were established between the 100g and 500g loads, and the 300g and the 500g loads of the small and large glove conditions; and between the 100g and 500g loads of the best-fitting glove condition.

Neoprene glove material results, as seen in Table XLIX indicate no significant differences for Flexor Digitorum Superficialis muscle activity responses. For the Flexor Pollicus Longus muscle activity, significant differences ($p<0.05$) were found between the 100g and 500g loads for the small, best-fitting and large glove conditions. Significant differences ($p<0.05$) were calculated between the 100g and 300g loads for the small glove condition; and between the 300g and 500g loads for the large glove condition. Significant differences ($p<0.05$) were determined between the 100g and 300g loads; and the 300g and 500g loads for the small and the best-fitting glove conditions for Extensor Carpi Ulnaris muscle activity. Furthermore, Extensor Carpi Ulnaris muscle activity responses elicited significant differences ($p<0.05$) for the large glove condition between the 100g and 300g; and the 100g and 500g loads.

Both the Extensor Carpi Radialis and Flexor Carpi Radialis muscle activity responses resulted in significant differences ($p<0.05$) between the 100g and 500g, and the 300g and the 500g loads for the small and large glove conditions; and between the 100g and the 500g loads of the best-fitting glove condition. The Flexor Carpi Ulnaris muscle activity responses elicited a single significant difference (p<0.05) between the 100g and the 500g loads of the best-fitting glove condition.

Table L: A comparison of the masses across the barehanded condition, the best-fitting neoprene and the best-fitting nitrile conditions for muscle activity responses (mV) during tactility test. Significant differences (p<0.05) are indicated by p values. n.s. specifies no significant differences (p<0.05). FDS = Flexor Digitorum Superficialis, FPL = Flexor Pollicus Longus, ECU = Extensor Carpi Ulnaris, ECR = Extensor Carpi Radialis, FCU = Flexor Carpi Ulnaris, FCR = Flexor Carpi Radialis

			Barehanded		Best fit nitrile		Best fit neoprene	
		Mass	100	300	100	300	100	300
FDS	Barehanded	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000010	0.000010	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	0.034484	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FPL	Barehanded	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000010	0.000010	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.00010	0.00017	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000465	0.029301
ECU	Barehanded	300	0.000010		n.s.	n.s.	n.s.	n.s.
		500	0.000010	0.000010	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	0.000215		n.s.	n.s.
		500	n.s.	n.s.	0.000010	n.s.	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000010	0.000308
ECR	Barehanded	300	0.033611		n.s.	n.s.	n.s.	n.s.
		500	0.000010	0.000016	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000325	n.s.
FCU	Barehanded	300	n.s.		n.s.	n.s.	n.s.	n.s.
		500	0.000010	0.000010	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	n.s.		n.s.	n.s.
		500	n.s.	n.s.	0.002249	n.s.	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
FCR	Barehanded	300	0.003541		n.s.	n.s.	n.s.	n.s.
		500	0.000010	0.000010	n.s.	n.s.	n.s.	n.s.
	Best fit nitrile	300	n.s.	n.s.	0.001766		n.s.	n.s.
		500	n.s.	n.s.	0.000010	n.s.	n.s.	n.s.
	Best fit neoprene	300	n.s.	n.s.	n.s.	n.s.	n.s.	
		500	n.s.	n.s.	n.s.	n.s.	0.000011	n.s.

Table L indicated the significant differences (p<0.05) between loads within the barehanded, and best-fitting glove conditions. It can be seen that there are significant differences (p<0.05) between the 100g and the 500g loads; and between the 100g and the 300g loads of the responses of each muscle's barehanded condition.

The Flexor Digitorum Superficialis muscle activity responses resulted in a further significant difference ($p<0.05$) between the 300g and the 500g loads within the best-fitting nitrile glove condition. Significant differences ($p<0.05$) were calculated between the 100g and the 500g loads; and the 300g and the 500g loads of both the best-fitting glove conditions. The muscle activity responses of the Extensor Carpi Ulnaris muscle elicited significant differences ($p<0.05$) between the 100g and the 300g loads of the barehanded condition; and between the 100g and the 300g loads, and the 100g and the 500g loads of the best-fitting nitrile glove materials. Further significant differences ($p<0.05$) were calculated between the 100g and the 500g loads; and between the 300g and the 500g loads of the best-fitting neoprene glove condition. For the Extensor Carpi Radialis muscle responses, significant differences ($p<0.05$) were found between the 100g and the 300g loads, and between the 100g and the 500g loads of the barehanded condition and the neoprene best-fitting glove condition, respectively. A single additional significant difference ($p<0.05$) was determined for the Flexor Carpi Ulnaris muscle activity responses, between the 100g and the 500g loads of the best-fitting nitrile glove condition. Lastly, for the Flexor Carpi Radialis muscle activity responses, significant differences ($p<0.05$) were found between the 100g and the 300g loads of both the barehanded and the best-fitting nitrile glove conditions. Furthermore, significant differences ($p<0.05$) were found between the 100g and the 500g loads of both the best-fitting glove conditions.

CHAPTER V

DISCUSSION

INTRODUCTION

This study investigated the effects of glove fit on task performance, and the human operator responses as a result of varying glove fit. The glove characteristic which was the predominant concern when regarding the results was that of fit. However, gloves of varying materials, namely a neoprene and nitrile glove were assessed, and the different responses measured due to material type were also considered. Bellingar and Slocum (1993) attributed certain task performance decrements to poor fit, as well as to the thickness and flexibility of the glove material. The following analysis regards the varying fit and material effect of gloves, in addition to the comparison of barehanded work to gloved work. Each component of the collection of performance responses is discussed.

MAXIMUM FORCE TEST

As seen in Table V (page 54) no significant differences ($p<0.05$) were found between conditions for participants' maximal force exertion, in either a pushing or pulling direction. However, as indicated in Figure 12 and Figure 13 (page 57), significant differences were calculated between conditions for the muscle activity responses. It is illustrated that both the Extensor Carpi Radialis and the Flexor Carpi Radialis muscles were significantly ($p<0.05$) affected by glove material. During the maximum pulling task, the best-fitting nitrile glove condition rendered significantly lower Flexor Carpi Radialis muscle activation than the best-fitting neoprene glove condition. This may be explained by the thinner material of the nitrile glove than the neoprene glove (Table I, page 33), as it has been found that glove thickness influences hand biomechanics (Sudhakar *et al.*, 1988). This causes an increase in the length and thickness of the digits thereby affecting forearm flexors and extensors.

Inconsistent with this finding is that during the maximum pulling task, the Extensor Carpi Radialis muscle was significantly ($p<0.05$) more activated during the thinner nitrile large glove condition than during the thicker neoprene large glove condition. It is understood that wrist extensor muscles are more sensitive than flexors to glove conditions (Larivière *et al.*, 2004). Although this could not be conclusively established from this investigation, considering the fact that significant differences ($p<0.05$) were found for both extensor and flexor muscles when comparing the barehanded condition with the best-fitting conditions of both the nitrile and neoprene materials (Figure 13, page 57), perhaps the glove fit factor is the predominant factor affecting the extensors. Therefore, although the neoprene material is 0.22mm thicker than the nitrile material, and therefore expected to elicit higher muscle activity, as regards the large glove conditions, the size effect was dominant, particularly for the more sensitive extensor muscles, therefore negating the thickness effect.

As seen in Figure 13 (page 57), during the maximum pushing task, the barehanded condition rendered significantly higher ($p<0.05$) Extensor Carpi Ulnaris muscle activity responses than the nitrile best-fitting glove condition. During the same task, the Flexor Carpi Radialis muscle activity was significantly lower during the barehanded condition than during the neoprene best-fitting glove condition. It is understood that gloves may alter the recruitment of the forearm muscles (Kovacs *et al.*, 2002), and that there are conflicting findings regarding the effect of glove use on muscle activity (Mital *et al.*, 1994). It can therefore be expected that inconsistent findings were found. The contradicting muscle activity responses for the extensor and flexor muscles may once again be explained by the varying thickness between the nitrile and the neoprene glove materials. As the best-fitting condition was expected to yield results the most similar to that of the barehanded condition, and the nitrile glove rendered lower muscle activity, it could be concluded that a thinner glove material could offer the best trade-off for safety and performance. However, it must be acknowledged that this only occurred for a single muscle.

Contradictory to findings from Hägg and Milerad (1997), who stated that Flexor Digitorum Superficialis activation increases as a result of additional finger load caused by glove stiffness, no significant differences (p<0,05) were found between the neoprene and nitrile glove materials for this muscle during either the maximum pushing or pulling task. This may be due to the fact that the materials are of a similar composition, and despite the increased thickness of the neoprene material, the flexibility of the glove materials was similar.

Considering both the muscle activity and the force responses, it can be seen that force production yielded no significant (p<0.05) differences with different conditions; however, muscle activity was significantly (p<0.05) affected. Significant differences (p<0.05) were only found between varying glove materials, not glove sizes, and results were incongruent between muscles. This suggests that wearing a glove of nitrile or a neoprene material (thickness 0.38mm-0.66mm), compared with being barehanded, will not influence maximal force production in either a pushing or pulling direction. Furthermore, varying glove fit will not influence maximal force production in either a pushing or pulling direction. Muscle recruitment during these tasks, however, will be affected, particularly between glove materials or between barehanded work and gloved work. It could be tentatively suggested that extensor, as opposed to flexor, muscle activity, will more likely to be higher due to ill-fitting gloves. Therefore, when selecting a glove for a maximal pushing or pulling task, where possible, it appears from this investigation, that a thinner glove material would elicit a lower incidence of MSD risk, and glove size would not interfere significantly with task performance or human operator responses. Further evidence of this was the outcome of the participants' perceptual responses (Table IX, page 58). There were no significantly (p<0.05) increased ratings of perceived exertion with glove use, or varying glove material or size. Fleming *et al.* (1997) stated that glove condition and the muscle action during a handgrip have a distinct influence on perception. Furthermore, Borg (1982) concluded that perceived exertion is the single best indicator of the degree of physical pain being experienced. Participants did not feel that any of the glove conditions elicited significant exertion.

MAXIMUM TORQUE TEST

Figure 14, Figure 15 and Figure 16 (page 60 and page 61) illustrate performance responses during the torque test, including peak torque, total work and average power, respectively. All of these performance parameters yielded significant results, as expected from the literature (Mital *et al.*, 1994; Shih and Wang, 1997).

All of the performance parameters indicated a similar trend of results when comparing the barehanded condition with the best-fitting glove conditions of both materials. It can be seen that significantly higher ($p<0.05$) peak torque, total work and average power was accomplished with a best-fitting glove as opposed to a being barehanded, for both nitrile and neoprene gloves. This is in agreement with Mital *et al.* (1994) who determined that torque exertions increase with gloves. Although perceptual responses do not indicate any significant responses ($p<0.05$) between being barehanded, and using gloves (Table XVI, page 63), it was observed that participants appeared more comfortable exerting maximal torque with a glove as opposed to being barehanded.

Comparing glove sizes and materials, it can be seen that for both peak torque (Figure 14, page 60) and average power (Figure 16, page 61), participants elicited greater results with a best-fitting condition, as compared with a small glove condition. This was found to be true for the neoprene glove material for peak torque, and the nitrile glove material for average power. The best-fitting glove conditions rendered better torque performance results than the large glove conditions; however, this comparison was not found to be significant ($p<0.05$).

It could be expected that the small glove condition would elicit significantly ($p<0.05$) lower torque performance responses compared with a best-fitting glove, due to hand movement impediments. Bellingar and Slocum (1993) assessed the effects of protective gloves on hand movement, during which participants had to tighten/untighten a container cap. This task could be likened to the torque movement generated by participants within the current study. It was determined that the protective glove decreased the amount of abduction/adduction the hand was able to complete. This interference with hand movement may be the attributing factor to decreased torque performance when donning a smaller than optimal glove size.

When considering muscle activity responses during the maximum torque test (Figure 17, page 63), it was found that the Extensor Carpi Ulnaris muscle activity was significantly ($p<0.05$) less during the barehanded condition than during the nitrile or neoprene best-fitting conditions. This follows the increased torque performance results discussed previously. This contradicts Mital *et al.* (1994) who found that an increase in torque exertion does not reflect a corresponding increase in muscle activation. However, this was only found to be true for one muscle, which was an extensor muscle and therefore potentially the most susceptible to the glove condition. The Flexor Digitorum Superficialis, Flexor Pollicus Longus, Extensor Carpi Radialis, Flexor Carpi Ulnaris and Flexor Carpi Radialis muscles did not incur increasing muscle activity between barehandedness and wearing a glove. Therefore, in agreement with Mital *et al.* (1994) there was minimal loss of muscular exertion at the glove-hand interface during torque tasks, but there was an amplification of muscular activity transmitted onto the workpiece. This suggests that during a maximal torque task, wearing a well-fitted glove as opposed to working barehanded could increase performance and ameliorate onset of fatigue and MSD risk.

A further significant difference ($p<0.05$) to be discussed from the muscle activity responses during the torque test was that between the large nitrile glove condition and the large neoprene glove condition for the Flexor Digitorum Superficialis muscle (Figure 17, page 63). The neoprene glove elicited significantly ($p<0.05$) higher muscle activity than the nitrile glove condition. Hägg and Milerad (1997) found that Flexor Digitorum Superficialis activation increased as a result of additional finger load caused by increased glove stiffness. The glove composition of the nitrile and neoprene materials was not noteworthy during the maximum pushing and pulling tasks; however, Kong and Lowe (2005) established that activities of the flexor muscles are notable in horizontal handle orientation, such as that during the study's torque exertion test. Therefore, the increased Flexor Digitorum Superficialis muscle activity during the neoprene condition as compared with the nitrile glove condition may be attributed to material thickness difference and the consequent amplified neoprene glove stiffness, which is a standard feature for this handle orientation.

There were no further significant differences ($p<0.05$) calculated for muscle activity responses during the torque test. No corresponding significant difference ($p<0.05$) was found between the best-fitting condition and the small glove condition, as seen in Figure 14 (page 60) and Figure 16 (page 61) for torque performance responses. Therefore, a best-fitting glove results in significantly greater torque performance than a restricting small glove, without increased muscle exertion, and consequent MSD risk. Donning a glove appears to enhance torque performance as compared to barehanded work. Torque tasks with a best-fitting glove condition are preferable to those with a small glove.

PRECISION OF FORCE TEST

Participants' precision of force was assessed by calculating the force trend, and the mean deviation from the force trend. Therefore, the relative trend that participants' force exertion and muscle activity responses followed over a minute ($\%.min^{-1}$) was calculated, as well as the mean deviation of the force exertion (N) and the muscle activity (mV) responses from this trend.

There were no significant differences ($p<0.05$) calculated between glove conditions for the force exerted in either a pushing or pulling direction by participants (Table XVII, page 64). It has been stated that the best way to assess glove effect is with sub-maximal exertions (Larivière *et al.*, 2004), and that that glove effects would be different under different levels of exertion (Bishu *et al.*, 1994). However, when comparing the maximal force exertion responses (Table V, page 54) with the force responses during the precision of force test (Table XVII, page 64), whereby a sub-maximal force was exerted, both tests elicited no glove effect.

The lack of glove effect during the precision of force test for pushing and pulling force indicates that glove fit does not significantly ($p<0.05$) influence force precision performance. This was further indicated by participants' perceptual responses. Table XXII (page 68) illustrates that no significant differences ($p<0.05$) were reported between conditions, indicating that participants experienced no significantly different perceived exertion effects between glove sizes and materials.

Muscle activity responses were found to be significant between conditions (Figure 18 and Figure 19, page 67) for the force trend results. The Flexor Pollicus Longus and Extensor Carpi Ulnaris muscles rendered significant differences ($p<0.05$) for the pulling and the pushing task, respectively.

The percentage change in muscle activity over a minute for the Flexor Pollicus Longus muscle during the pulling task was significantly ($p<0.05$) less for the large nitrile glove condition than it was for the best-fitting glove condition (Figure 18, page 67). This was unexpected, as gloves which fit the worker well are expected to maximise the transfer of muscular force to grip force, reducing the amount of over-gripping required to maintain desired grip force (Kovacs *et al.*, 2002). However, with the best-fitting glove condition, not only was the change in muscle activity significantly ($p<0.05$) higher than for the large glove condition but participants were found to be overcompensating, as opposed to under-compensating as for all of the other conditions. This was an isolated outcome for the Flexor Pollicus Longus muscle, as the other selected muscles elicited no significant differences ($p<0.05$) between glove sizes or materials. Furthermore, no significant differences ($p<0.05$) were calculated between the barehanded and best-fitting glove conditions.

As seen in Figure 19 (page 67) the change in muscle activity over a minute for the Extensor Carpi Ulnaris muscle was significantly different ($p<0.05$) between the neoprene small and large glove conditions. The small glove condition produced a significantly larger change in muscle activity than the large glove condition. Once again, this contradicts expectations, as Kovacs *et al.* (2002) determined that larger gloves create slipping between the glove-handle interface, which creates a slight extension of the wrist, resulting in the grip occurring at a less optimal muscle length and consequently more sensitive muscle activity responses. Again, this was only found for a single muscle, the Extensor Carpi Ulnaris, as the other tested muscles did not indicate significant differences between either glove sizes and materials, or between the barehanded condition and the best-fitting glove conditions.

Therefore, results from the force trend data, which indicate the relative change in muscle activity over a minute, suggest that muscle activity during force precision tasks does not differ with glove use or glove fit. Glove effect does not cause muscle activity to either over or under-compensate.

Mean deviation from the force trend was also analysed for each of the muscles tested for each condition (Figure 20, page 68). The Flexor Digitorum Superficialis and the Flexor Carpi Ulnaris muscles elicited significant differences ($p<0.05$) during the precision of force pushing task. Firstly, considering the comparison of the barehanded condition with the best-fitting conditions, it is apparent that the Flexor Carpi Ulnaris muscle activity deviated significantly ($p<0.05$) more from the force trend during the nitrile best-fitting condition than during the barehanded condition. Therefore, force precision when wearing a best-fitting glove was not preferable to being barehanded. This was expected, as according to Westling and Johansson (1984), gloves interfere with tactile feedback, and consequently grip force control. The neoprene best-fitting glove condition produced significantly ($p<0.05$) higher Flexor Carpi Ulnaris muscle activity responses than the nitrile best-fitting glove condition. Therefore, when selecting a glove for a task requiring force precision, a thinner material may be preferable.

Comparing glove sizes and materials, from Figure 20 (page 68), it was found that the Flexor Digitorum Superficialis muscle elicited significantly ($p<0.05$)

higher activity during the nitrile large glove condition than the best-fitting glove condition. The same was found for the Flexor Carpi Ulnaris muscle and the neoprene glove material. Therefore, when considering mean deviation from the trend, force precision was less taxing, specifically for the flexor muscles, when donning an optimally fitted glove than a glove which was too big, for both materials. This finding would support the hypothesis that an optimally fitted glove would be preferable to a large glove. This concurs with Kovacs *et al.* (2002) who discovered that glove fit may have a significant ($p<0.05$) effect on flexor muscle activity when a glove which is larger than best-fitting is used.

Muscle activity during precision of force was therefore affected by glove size and material. Due to the fact that there were no corresponding significant differences ($p<0.05$) measured between conditions for force output, it could be concluded that force precision tasks require consideration when selecting gloves. Inappropriate glove selection may lead to the quicker onset of fatigue, and therefore MSD risk (Sudhakar *et al.*, 1988).

TACTILITY TEST

For the tactility assessment, participants were required to use a pulp pinch, which involves digit one and digit two (Sollerman and Sperling, 1978). Three loads were lifted; a 100g, 300g and 500g mass, barehanded and with each gloved condition. The pressure exerted by both digits during each trial was measured, as well the muscle activity required to complete the task.

Figure 21 and Figure 22 (page 71) illustrate the pressure exerted by digit one (F1) and digit two (F2), respectively. The conditions have been compared across each mass, as well as the masses compared within each condition.

It can be seen that there was a load effect on the barehanded condition and the neoprene best-fitting condition, as the 500g mass elicited significantly ($p<0.05$) higher grasp force than the 100g mass (Figure 21, page 71). Furthermore, there was a glove effect, as significant differences ($p<0.05$) were calculated between the barehanded condition and both best-fitting glove conditions at 100g and 300g. This suggests that tactile perception is affected by donning a glove, particularly when the glove is of a thicker material, such as the neoprene glove material (0.66mm). This is additionally supported by the significant differences ($p<0.05$) between the nitrile best-fitting and the neoprene best-fitting glove conditions for the 300g and the 500g loads. The neoprene material elicits significantly ($p<0.05$) more pressure, which may be attributed to the thickness of the material.

Significant differences ($p<0.05$) were established between the nitrile small and large glove conditions; and the small and best-fitting conditions for the grasp pressure exerted by digit one for the 100g mass. This indicates that glove fit influenced grasp pressure. The best-fitting glove condition rendered significantly ($p<0.05$) lower grasp pressure than the small glove condition. Therefore, an optimally fitted glove provided the best tactile feedback as compared with a glove which was too tight. The small glove condition was also found to elicit significantly ($p<0.05$) higher grasp pressure than the large glove condition. This result was unexpected, as a glove which provides excess ease would cause the glove to slide around on the participant's hand and result in tactile feedback interference (Westling and Johansson, 1984). However, Sweeney (2008), hypothesized that gloves which are too snug, may decrease dexterity and cause discomfort. Perhaps the smaller-than-optimal glove size resulted in a decrease in friction between the tactile receptors on the skin, and the object thereby influencing the magnitude of the pinch force (Westling and Johansson, 1984).

There was no glove effect recorded for the grasp pressure exerted by digit two (F2) (Figure 22, page 71). A load effect was found for the barehanded and the neoprene large glove conditions between the 100g and the 500g loads.

Considering the effect of glove condition and mass on muscle activity responses, Figure 23 (page 75), Figure 24 (page 76), Figure 25 (page 77),

Figure 26 (page 78) and Figure 27 (page 79) and Figure 28 (page 80) illustrate the significant differences ($p<0.05$) during the tactility test.

A load effect was consistent for all of the tested muscles; the trend being that an increased load resulted in an increase in the muscle activity response. The load effect was particularly evident between the greatest load difference: the 100g and the 500g loads. This is in agreement with an investigation by Bishu *et al.* (1994). The authors found that there was an increasing load effect on responses during a tactility test, at sub-maximal exertions.

The same investigation determined that a marginal glove effect at sub-maximal exertions could be expected for tactility responses (Bishu *et al.*, 1994). For each of the muscles, significant differences ($p<0.05$) were found between the barehanded condition and the best-fitting glove conditions. This was predominantly seen for the 500g mass. It was unexpected that the barehanded condition elicited significantly ($p<0.05$) higher muscle activity for all the muscles than the best-fitting conditions. Due to the lack of interference from the glove material, it was anticipated that participants would require less muscular exertion when barehanded to lift the loads. However, many authors (Wilkes *et al.*, 1973) have reported the importance of friction on grip. As friction varies, grip may alter significantly between different materials, and for the same material under different conditions. The glove materials provided increased friction between the hand and the loads. The nitrile glove was described as having an anti-slip finish; and the neoprene glove as having ‘tractor tread’ grip (Table I, page 33). These material qualities resulted in the significantly ($p<0.05$) increased muscle activity when lifting loads barehanded, as opposed to when donning gloves. This effect was also commented on by participants.

There were no significant differences ($p<0.05$) established between glove materials of the same size. Therefore, the difference between the neoprene and the nitrile materials, and the thickness discrepancy, was not marked enough to establish a preferable material for tactile feedback. Significant differences ($p<0.05$) were determined between glove sizes, however. This was found to be particularly evident between the small and large, and the best-fitting and large glove conditions. The large glove conditions caused significantly higher ($p<0.05$) muscle activity responses. This was a probable result, as the excess ease provided by the larger glove would hinder the transmission of impulses from the mechanoreceptors, thereby causing tactile sensitivity to be reduced. This resulted in the hand becoming increasingly unable to gain the necessary tactile feedback to perform the task, resulting in increased muscle activity (Buhman *et al.*, 2000).

Tactile feedback appeared to be affected by glove use, and primarily by load mass. A glove which was too large impeded tactility the most. Contrary to what may be expected, being barehanded was not the optimal condition for maximum tactility and minimal muscle exertion. This was attributed to friction. The best-fitting condition rendered the most desirable results regarding muscle activity.

SPEED AND ACCURACY TEST

Only performance responses were considered for this test, including reaction time (Figure 29, page 82) and deviation from target (Figure 30, page 83).

Both reaction time and target deviation elicited significant differences ($p<0.05$) between the barehanded condition and the best-fitting neoprene glove condition. The neoprene best-fitting glove resulted in significantly ($p<0.05$) higher reaction time and target deviation values. The same was not found for the best-fitting nitrile glove condition. Once again, this could be a result of the increased thickness of the neoprene material compared with the nitrile material. This finding is further supported by Bensel (1993), who tested glove types and found that, relative to bare-handed performance, gloves limited the speed at which the work could be accomplished. This was found to be particularly true when excess glove ease and thickness were afforded by the glove (Williams, 1979; Tremblay, 1989). There were, however, no significant ($p<0.05$) glove size effects found during this test.

DEXTERITY TEST

Dexterity is a performance component which has been found to be adversely affected by glove use (Mital *et al.*, 1994; Muralidhar *et al.*, 1999). This was further confirmed by the results of this investigation (Figure 31, page 84). The best-fitting condition of the thicker neoprene glove material produced significantly higher ($p<0.05$) dexterity time results than the barehanded condition, and the nitrile best-fitting glove condition. Excess glove thickness has been found to cause a loss of dexterity (Williams, 1979; Tremblay, 1989).

Another glove characteristic which reduces dexterity is glove sizing (Havenith and Vrijkotte, 1994). The large glove condition was found to result in significantly ($p<0.05$) higher dexterity times than both the small and the best-fitting glove conditions. The small condition and the best-fitting condition were not found to produce significantly ($p<0.05$) different dexterity scores. Therefore, a glove which is smaller than an optimally fitted glove may not interfere with dexterity during a task.

Findings of this investigation concur with those of both Bellingar and Slocum, (1993) and Tremblay (1989), who concluded that redesigning work gloves to conform to the hand, wrist and forearm, or developing a thinner glove material would improve dexterity performance with gloves, and a tighter-fitting glove would obstruct dexterity the least.

CONCLUSION

Results suggest that maximal force was either unaffected, or, in the case of torque performance, optimised, with glove use. However, in this case, a glove which fits optimally was preferable, and a glove which was small and hindered hand movement should not be donned. When a task requires force precision, if a glove must be donned, one which has better fit and is of a thinner material would be preferable. However, this outcome was concluded for only mean deviation from the force trend data, and only for the Flexor Digitorum Superficialis and the Extensor Carpi Ulnaris muscles. It was however evident from grasp pressure assessments that tactile perception was considerably affected by load lifted, for all muscles tested. The glove effect on tactility suggested that wearing a best-fitting glove was preferable to being barehanded, or donning a glove which was too large. Speed and accuracy results established no glove fit effect, but do suggest that a glove material which is too thick would be detrimental to this component of task performance, compared with completing the task barehanded, or with a glove of thinner material. Dexterity results were the most conclusive regarding glove fit and material, as the larger glove size was found adversely to affect dexterity times, as did the thicker neoprene glove material.

It can be seen that although there is a specified glove thickness and material which often take precedent within a given industry due to environmental hazards, the task at hand should be considered, including the attributes of the task performance. Proper selection of appropriate gloves (Sorock *et al.*, 2004a), and consideration of glove fit, particularly for tasks involving force precision, tactile perception and dexterity, would enhance task performance.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Establishing the relationship between glove fit and task performance, and glove fit and human operator responses provides knowledge which could introduce a simple intervention strategy into an extensive variety of industries. This relationship has been surprisingly under-researched, with the majority of glove studies focussing on glove material and thickness, and failing to isolate the effect of glove size and this hand/glove interface. Within this investigation, the three differing glove fit conditions for a single glove material and type, tailored to each participant, presented a unique opportunity to investigate the effects of manual performance of protective gloves differing along only one physical dimension. Previous research has resulted in conflicting conclusions regarding the influence of glove use; however, it has generally been accepted that gloves adversely affect performance (Griffin, 1944; Hertzberg, 1955; Bradley, 1969b; McGinnis *et al.*, 1973; Cochran *et al.*, 1986; Muralidhar and Bishu, 1994). The current study undertook a holistic approach with the endeavour being explicitly to examine the link between glove fit and task performance and the impact of varying fit on the human operator.

SUMMARY OF PROCEDURES

This study was concerned with elucidating the effects of glove fit, of two varying materials, on components of task performance. The impact of the hand/glove interface on the human operator was also investigated.

The investigation was laboratory-based and took place in the Human Kinetics and Ergonomics Department at Rhodes' University, Grahamstown. The research design was such that a battery of tests was executed with seven different conditions (i.e. each test was performed seven times). The seven conditions which were investigated were a barehanded condition and six gloved conditions, of which there were two materials (nitrile and neoprene) and three glove sizes (smaller-than-best-fitting, best-fitting, larger-than-best-fitting) in both materials (two materials * three sizes + barehanded = seven). The components of task performance which were assessed included: maximum force and torque, precision of force, tactility, dexterity, and speed and accuracy. Performance variables were measured, as well as human responses. The human responses were analysed using electromyography of six muscles: the Flexor Digitorum Superficialis, Flexor Pollicus Longus, Extensor Carpi Ulnaris, Extensor Carpi Radialis, Flexor Carpi Ulnaris and Flexor Carpi Radialis. Participants' perceptual responses were accounted for using the Rating of Perceived Exertion scale.

The maximum force and precision of force tests necessitated the use of the DataLogger and a load cell, whereby both a pushing and pulling force were exerted. For the test of maximum force, maximal effort was applied for five seconds over three trials, with a 30-second break between each trial. The precision of force test required participants to exert a sub-maximal (30% of maximum force) force for 60 seconds, without visual or verbal feedback. For the torque test, the Cybex isokinetic dynamometer was employed, providing participants' peak torque, total work and average power results as participants grasped a convoluted knob and wielded maximum torque clockwise and anticlockwise in a horizontal plane. A Minnesota Dexterity Board, and touch screen interface rendered dexterity scores and participants' speed and accuracy effects, respectively. Pressure sensors placed on digits one and two provided grasp pressure data, which was used as a measure of participants' tactility, as participants grasped and lifted three loads (100g, 300g and 500g).

Thirty-five male participants were recruited from the Rhodes' University population who voluntarily participated in a single, two-and-a-half hour session. Participants were provided with information about the experimental procedure, and were asked to sign informed consent. Anthropometric data were collected and participants were familiarised with the required tasks. Participants then executed the battery of tests with the seven conditions (all randomised through permutations), during which the performance and human responses were measured.

Prior to testing, electrical activity of maximal voluntary contractions (MVCs) of the six muscles were obtained in order for intra-individual comparisons of muscle responses between the different conditions to be carried out.

SUMMARY OF RESULTS

Many of the results established were contrary to those which were expected. This was however congruent with the conflicting nature of the results from previous studies. When exerting maximum force, there were varying responses depending on the direction of the applied force. Maximum pushing and pulling force appeared to be unaffected by varying glove size or material. However, muscle activity during such a task responded differently between the two glove materials, indicating that the thinner, nitrile material elicited lower muscle activity responses. Maximum torque force was found to be optimised with glove use. It was established that performance responses were best with a best-fitting glove when compared with barehanded performance, for both materials, and there was also minimal loss of muscular exertion at the glove-hand interface, suggesting that wearing a well-fitted glove as opposed to working barehanded would not lead to quicker onset of fatigue and MSD risk.

Precision of force, which is regarded in the literature as being a more favourable reflection of glove performance than maximum force assessments, was assessed by the relative trend of the force and muscle activity and the mean deviation from this trend.

There was no glove fit or material effect established for the force exerted. Furthermore, results from the force trend data indicated that muscle activity during force precision tasks does not differ with glove use or glove fit. Glove effect did not cause muscle activity to either over or under-compensate.

However, the mean deviation from the force trend data suggested that force precision was less taxing, specifically for the flexor muscles, when donning an optimally-fitted glove rather than a glove which was too big, for both materials, but wearing a best-fitting glove was not preferable to being barehanded. In addition to that, when selecting a glove for a task requiring force precision, a thinner material (nitrile as opposed to neoprene) was found to be favourable.

There appeared to be a significant load effect on tactility. An increased load resulted in an increase in both grasp pressure and muscle activity. Grasp pressure, and therefore tactile perception was affected by donning a glove, as compared to being barehanded, particularly when the glove was the thicker, neoprene glove material. However, when a glove was necessitated, an optimally-fitted glove provided the best tactile feedback. Muscle activity responses produced an interesting result, as being barehanded was not the optimal condition for maximum tactility and minimal muscle exertion. The best-fitting condition rendered the most desirable results regarding muscle activity.

Findings for the speed and accuracy component of task performance concluded that both reaction time and target deviation were higher when a best-fitting neoprene glove was donned, as opposed to completing the task barehanded. The nitrile glove did not follow this trend, suggesting that a glove of increased thickness would limit speed and accuracy. However, glove fit did not appear to affect this performance component for either material.

This conclusion could also be drawn for dexterity performance. In addition to this, dexterity was also considerably affected by glove fit, as large glove condition, which had excess ease, resulted in higher dexterity times than both the small and the best-fitting glove conditions. Therefore, either a glove which fits optimally, or one which was smaller than the optimally-fitted glove was best for dexterity performance.

RESPONSES TO HYPOTHESES

Hypothesis 1: performance responses

This proposed that the performance responses would be the same between the barehanded condition, and the best-fitting glove conditions. Furthermore, the hypothesis tested was that the smaller-than-best-fitting (optimal) glove condition, the best-fitting glove condition and the larger-than-best-fitting glove condition would elicit the same results.

H_o: $\mu_{\text{bare-handed responses}} = \mu_{\text{optimal glove responses}}$

$\mu_{\text{small glove responses}} = \mu_{\text{optimal glove responses}} = \mu_{\text{large glove responses}}$

Where: responses = components of performance: maximum pushing and pulling force; peak torque, total work, average power; precision of force in a pushing and pulling direction; dexterity; grasp force as a measure of tactility; movement time and deviation from target as a measure of speed and accuracy.

Maximum pushing and pulling force

There was no glove effect found for the maximum pushing and pulling task. The null hypothesis is therefore accepted.

Torque

Different responses were measured between the barehanded condition and donning best-fitting gloves, as well as between gloves of varying fit. The null hypothesis is therefore rejected.

Precision of force

There was no glove effect found for force precision. The null hypothesis is therefore accepted.

Tactility

Tactile perception was found to be affected by glove use and by wearing different fitting gloves necessitating the rejection of the null hypothesis.

Speed and accuracy

It was established that there was a difference between working barehanded, and working with an optimally-fitted glove. There were, however, no differences found between gloves of different fit. The first part of the null hypothesis is therefore rejected. The second part of the null hypothesis has been accepted.

Dexterity

It was determined that dexterity was influenced by both glove fit, and wearing an optimally-fitted glove as compared to being barehanded. The null hypothesis is confidently rejected.

Hypothesis 2: human responses

This proposed that the participants' feedback would be the same between the bare-handed condition and the best-fitting glove condition; and between the smaller-than-best-fitting (optimal) glove condition, the best-fitting glove condition and the larger-than-best-fitting glove condition.

H_a: $\mu_{\text{bare-handed responses}} = \mu_{\text{optimal glove responses}}$

$\mu_{\text{small glove responses}} = \mu_{\text{optimal glove responses}} = \mu_{\text{large glove responses}}$

Where: responses = muscle activity of six muscles, namely the Flexor Digitorum Superficialis, Flexor Pollicus Longus, Extensor Carpi Ulnaris, Extensor Carpi Radialis, Flexor Carpi Ulnaris, Flexor

Carpi Radialis; and perceptual responses (ratings of perceived exertion).

Maximum pushing and pulling

There were no differences recorded for perceptual responses. As regards muscle activity, differences were calculated between performing the task barehanded and with a glove which fits optimally. However, there was no discrepancy in responses between gloves which fitted differently. This concludes that the first part of the null hypothesis is accepted, but the second part of the null hypothesis is rejected.

Torque

There were no differences recorded for perceptual responses. The muscle activity responses differed between working barehanded and with a best-fitting glove, however not between working with gloves of different sizes. The first part of the null hypothesis is accepted, and the second part rejected.

Precision of force

There were no differences recorded for perceptual responses. Muscle activity when barehanded was not found to be different to muscle activity with an optimally-fitted glove. However, different sized gloves produced different muscle activity responses. Consequently, the first part of the null hypothesis has been accepted, and the second part has been rejected.

Tactility

Muscle activity differed between the barehanded condition and the best-fitting condition, as well as between different glove size conditions. The null hypothesis is therefore rejected.

CONCLUSIONS

The results of the current study emphasise the need to consider the requirements and components of a work task, as well as the anthropometrics of the worker doing the task, and consequently to select the most appropriate hand wear for the situation.

Prior research indicated that fit was an under-investigated and influential component of a glove. This study focussed on relevant components of performance and established that for a nitrile, or a neoprene glove, certain task elements require a glove which optimally fits the worker: other elements would be better performed barehanded, or with a thinner material (if possible). Other aspects of performance would not be affected by a standard glove size for all workers.

These results may have an impact on glove allocation for industrial tasks, and as a result the tasks may be most effectively performed, with the least amount of strain placed on the worker. Furthermore, a worker may be more inclined to comply with safety regulations should the protective gloves available not hinder the task to be completed, and are more comfortable to wear.

RECOMMENDATIONS

This study indicated that ill-fitting gloves are a relevant determinant of performance outcomes and human operator responses. Additional research is required to explore this effect, which would allow for successful transference of the data and conclusions to industry. Future investigations into glove effect on task performance and worker responses should consider the following recommendations:

1. Conditions of longer duration in order to assess the effects over the duration of a shift and to gain an understanding of gloves and muscle fatigue.

2. Similar studies should be conducted on workers in industry to ascertain whether the results found in this study are equivalent to those found for individuals with experience in performing tasks with gloves.
3. Glove sizes must be tested within a greater variety of glove materials. This would allow for better extrapolation of results to industry, as perhaps particular materials or degree of material thickness cause the glove fit effect to be emphasised.
4. Additional performance components should be tested, in order to supplement findings and make results applicable to an increased number of industry tasks.
5. Tests should be executed which combine performance requirements, for example, tasks which require both tactility and force.

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APPENDICES

APPENDIX A: GENERAL INFORMATION

Equipment checklist

Order of procedures

Protocol information for participants

Participant consent form

Equipment checklist

ADMINISTRATION

- Letter of information for the participant
- Informed consent form
- Data collection sheet

EQUIPMENT FOR TEST BATTERY

- Stadiometer – stature
- Tape measure – hand measurements
- Stop watch
- Chair with wooden blocks to adjust height (*2)
- Laptop (Acer 1 “Mike”)
  - Software = DataLogger
Fitts’
- DataLogger + electrodes
- Push/pull force sensor (and a just-in-case 1 for torque)
- Cybex
- Handle (and a just-in-case 1 for torque)
- 2 * pressure sensors (thumb and finger)
- 3 * grasp objects (100g, 300g, 500g)
- Touch screen
- Dexterity board
- Rating of perceived exertion scale
- GLOVES – material A (sizes 7, 8, 9, 10) and material B (sizes 7, 8, 9, 10)

ADDITIONAL EQUIPMENT

- Milton solution and cotton wool/paper towel
- Disposable Razors
- Tape for the pressure sensors
- Paper
- Pen

Order of procedures

BEFORE TESTING

- Are the DataLogger batteries charged?
- Cybex working

TESTING

- Laptop and DataLogger on
    - Software open
    - Analogue inputs prepped
    - USB connected

- Explanation of:
    - Protocol
    - Equipment
    - RPE
- Questions?
- Letter to the participant and signed consent

- Collect anthropometric data
    - Stature
    - Hand length
    - Finger length
    - Palm width
    - Palm circumference
- Choose best-fitting glove
- Brief protocol practice, if necessary

- Attach neutral strap
- Locate 6 * muscle positions - clean and shave
- Attach electrodes
- Check connections

→ START

- Explain and execute MVCs testing
    - o 2 repetitions for 5 seconds (each muscle)

→ STOP

- Select order of glove conditions
- Select order of tests
- Seat participant, and explain 1st test

→ START

- Complete all tests with all conditions (force precision after maximum force)

→ STOP

- Remove electrodes

AFTER TESTING

- Save data!!!
- Clean up

Protocol information for participants

Dear______________________.

Thank you for your offer to participate in this study, your assistance is very much appreciated. This letter of information will explain the aim of the project, the procedures to be followed, and the potential risks and benefits involved. Please read it carefully, and sign the accompanying consent form.

AIM OF THE STUDY

You will be required to perform various tasks, donning gloves of three different sizes and two different materials. The focus of this investigation is to assess the effect of glove fit on worker performance. The tasks to be completed include components of manual performance, including force production, dexterity, tactility, precision, and speed and accuracy. Your responses will be quantified by measuring muscle activity, force and pressure production, and documenting perceptual responses.

PROCEDURES

You will be required to attend one session at the Human Kinetics and Ergonomics Department. This will include a short habituation, during which your stature and hand anthropometric measurements will be taken; you will be verbally informed of the testing procedure; and you will have the opportunity to practise the tasks to be completed during testing. Thereafter the experimental protocol will be completed. The protocol will require you to have electrodes placed on six relevant muscles on your arm, and for you to carry out the test battery. You will execute each test seven times, once barehanded, and six trials with gloves of varying size, and material. There will be a test of force production, in a pushing and pulling direction, and torque. This will require you to exert maximum effort, in various directions, using a handle and a force sensor. For the torque experimentation, the CYBEX ® 6000, an isokinetic dynamometer will be used. A dexterity test using the Minnesota dexterity board will be executed, in addition to a grasp test, using pressure sensors as a measure of tactility. You will be required to exert a sub-maximum force, without visual or verbal aids, in order to assess precision. Lastly a test of speed and accuracy will be completed, based on Fitts' law, using a touch screen. Additionally, at the end of each force production test, you will be shown a scale, which will aid you to quantify your perceived exertion.

RISKS AND BENEFITS

It is highly unlikely that you will incur any injuries during this study, as the procedures involved are non-invasive, well-established, and safe. A possible risk is the development of muscular discomfort, which will dissipate quickly. If at any point you feel that you are unable to complete the protocol, you may stop the test.

The Department will however waiver any legal recourse against the researcher or Rhodes University in the unlikely event that an injury occurs.

Benefits include an increased knowledge of your body's capacity for work, and for the processes and equipment which will be utilized during the experimentation. Additionally, you will be contributing to an improved understanding of demands placed on industrial workers, and a potential intervention approach to make the workplace more comfortable, safe and efficient.

Thank you again for your participation, and cooperation.

Yours sincerely,
Jessica Stack (Bsc Hons – Human Kinetics and Ergonomics)

Participant Consent Form

I, ____________________, do hereby consent to participate in the study entitled: "THE EFFECT OF GLOVE MATERIAL CHARACTERISTICS, SPECIFICALLY FIT, ON TASK PERFORMANCE AND THE HUMAN OPERATOR". I agree that I have been fully informed, both verbally and in writing, of the procedures involved in this study. I have also been made aware of the potential risks associated with the protocol.

I realise that whilst my anonymity will be protected at all times, my results may be published or used for scientific and statistical purposes. I understand the conditions with which I am expected to comply for the duration of the tests, and any queries I have with regards to this have been answered to my satisfaction.

By voluntarily consenting to participating in this research I accept responsibility, whereby, should any be injury sustained, the Department and the researcher will not be held liable. I will inform the researcher immediately if at any point I experience distress or abnormality, and I am fully aware that I may withdraw from this study at any time.

I have read and understood the above information, as well as the information provided in the letter accompanying this form.

Signed at the Human Kinetics and Ergonomics Department, Rhodes University, on _____/_____/_____.

PARTICIPANT: ________________ (NAME) ______________ (SIGN)
WITNESS: ________________ (NAME) ______________ (SIGN)
RESEARCHER: ________________ (NAME) ______________ (SIGN)

APPENDIX B: TESTING SESSION

Data collection sheet

Rating of perceived exertion scale

MVC illustrations

Data collection sheet

Participant name_______________ Number_________________
Age_______________ Dominant hand __________

ANTHROPOMETRIC DATA

Variable	Measurement (mm)
Stature	
Hand length	
Finger length	
Palm width	
Palm circumference	

GLOVE CONDITIONS

Best-fitting glove size _________________

'Too small' size_________________

'Too big' size_____________

Self-selected best fit __________________

ORDER OF CONDITIONS/TEST BATTERY

Tests permutated = Force
Torque
Dexterity
Tactility
Speed and accuracy

Conditions permutated = Nit F
Nit S
Nit B
Neo F
Neo S
Neo B
BH

Test	1	2	3	4	5
Condition					
1					
2					
3					
4					
5					
6					
7					

DEXTERITY TEST

Condition	Dexterity time
1	
2	
3	
4	
5	
6	
7	

Comments:

TACTILITY TEST

Condition	1	2	3	4	5	6	7
Load							
1							
2							
3							

Loads = 100g
300g
500g

Comments:

PUSH/PULL FORCE TESTS

Condition	Max		Submax	
	1	2	3	4
1				
2				
3				
4				
5				
6				
7				

Maximum push
Maximum pull
Sub-maximum push
Sub-maximum pull

RESULTS

Condition	Force max push	Force submax push	Force max pull	Force submax pull
1				
2				
3				
4				
5				
6				
7				

Comments:

RATINGS OF PERCEIVED EXERTION

RPE	F (push max)	F (pull max)	F (push submax)	F (pull submax)	F (torque)
CONDITION					
1					
2					
3					
4					
5					
6					
7					

Comments:

Rating of perceived exertion scale

RPE SCALE

6.
7. VERY, VERY LIGHT
8.
9. VERY LIGHT
10.
11. FAIRLY LIGHT
12.
13. SOMEWHAT HARD
14.
15. HARD
16.
17. VERY HARD
18.
19. VERY, VERY HARD
20.

Maximum voluntary contractions illustrations

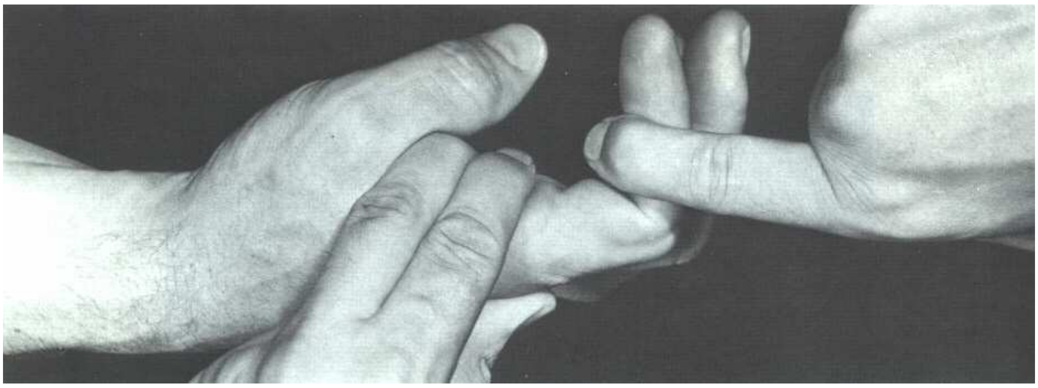


Figure 32: Flexor Digitorum Superficialis

Figure 33: Flexor Pollicus Longus

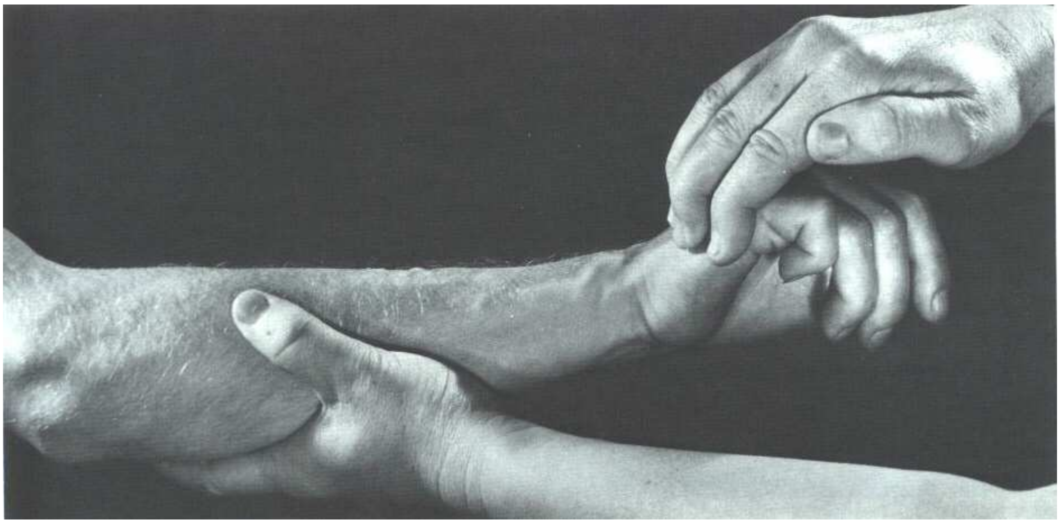


Figure 34: Extensor Carpi Ulnaris

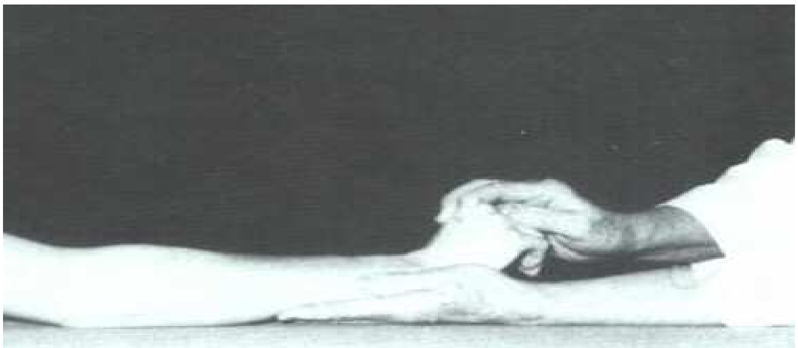


Figure 35: Extensor Carpi Radialis

Figure 36: Flexor Carpi Ulnaris

Figure 37: Flexor Carpi Radialis

APPENDIX C: DATA

ANOVA and post-hok tukey tables, with detailed p-values

Electromyography printout

Cybex printout

ANOVA and post-hok tukey tables

Rating of Perceived exertion

Maximum push

z	Degr. of – Freedom	F	p
MATERIAL	1	0.025	0.875484
SIZE	2	1.041	0.358492
MATERIAL*SIZE	2	0.394	0.675557

	Degr. of - Freedom	F	p
COND	2	0.976	0.382002

Maximum pull

	Degr. of - Freedom	F	p
MATERIAL	1	0.084	0.774152
SIZE	2	0.978	0.381282
MATERIAL*SIZE	2	0.216	0.806079

	Degr. of - Freedom	F	p
COND	2	0.418	0.659900

Torque

	Degr. of - Freedom	F	p
MATERIAL	1	0.0293	0.865182
SIZE	2	2.3487	0.103197
MATERIAL*SIZE	2	1.0223	0.365238

	Degr. of - Freedom	F	p
COND	2	0.8908	0.415049

Sub-maximum push

	Degr. of - Freedom	F	p
MATERIAL	1	1.285	0.264887
SIZE	2	2.540	0.086327
MATERIAL*SIZE	2	1.468	0.237528

	Degr. of - Freedom	F	p
COND	2	0.801	0.452853

Sub-maximum pull

	Degr. of - Freedom	F	p
MATERIAL	1	0.028	0.866961
SIZE	2	2.752	0.070932
MATERIAL*SIZE	2	0.315	0.730955

	Degr. of - Freedom	F	p
COND	2	0.364	0.696269

Dexterity

	Degr. of - Freedom	F	p
MATERIAL	1	6.763	0.013676
SIZE	2	18.902	0.000000
MATERIAL*SIZE	2	0.161	0.852011

	MATERIAL	SIZE	{1} - 89.543	{2} - 90.086	{3} - 98.914	{4} - 92.886	{5} - 92.457	{6} - 102.97
1	1	1		0.999856	0.000590	0.612477	0.738735	0.000129
2	1	2	0.999856		0.001259	0.769772	0.870238	0.000129
3	1	3	0.000590	0.001259		0.060953	0.036138	0.398549
4	2	1	0.612477	0.769772	0.060953		0.999955	0.000256
5	2	2	0.738735	0.870238	0.036138	0.999955		0.000186
6	2	3	0.000129	0.000129	0.398549	0.000256	0.000186	

	Degr. of - Freedom	F	p
Intercept	1	2393.679	0.000000
COND	2	42.195	0.000000000001

	COND	{1} - 75.743	{2} - 90.086	{3} - 92.457
1	DEXTERITY BH		0.000112	0.000112
2	DEXTERITY NITF	0.000112		0.454741
3	DEXTERITY NEOF	0.000112	0.454741	

Speed and accuracy

Reaction time

	Degr. of - Freedom	F	p
MATERIAL	1	10.170	0.003061
SIZE	2	6.478	0.002659
MATERIAL*SIZE	2	0.005	0.995420

	MATERIAL	SIZE	{1} - .46786	{2} - .47149	{3} - .48926	{4} - .48643	{5} - .49111	{6} - .50894
1	1	1		0.998811	0.204135	0.350226	0.135310	0.000592
2	1	2	0.998811		0.399842	0.592670	0.289874	0.001935
3	1	3	0.204135	0.399842		0.999664	0.999958	0.286802
4	2	1	0.350226	0.592670	0.999664		0.995857	0.160311
5	2	2	0.135310	0.289874	0.999958	0.995857		0.396196
6	2	3	0.000592	0.001935	0.286802	0.160311	0.396196	

	Degr. of - Freedom	F	p
COND	2	4.257	0.018123

	COND	{1} - .47223	{2} - .47149	{3} - .49111
1	SPEEDACC BH rxnt		0.994860	0.041275
2	SPEEDACC NITF rxnt	0.994860		0.032469
3	SPEEDACC NEOF rxnt	0.041275	0.032469	

Target deviation

	Degr. of - Freedom	F	p
MATERIAL	1	5.2021	0.028946
SIZE	2	2.8142	0.066951
MATERIAL*SIZE	2	4.1195	0.020478

	MATERIAL	SIZE	{1} - 7.5680	{2} - 7.6694	{3} - 8.1960	{4} - 7.8937	{5} - 8.5751	{6} - 8.0649
1	1	1		0.998746	0.153225	0.798990	0.002735	0.387128
2	1	2	0.998746		0.322291	0.951019	0.009294	0.637219
3	1	3	0.153225	0.322291		0.844548	0.677493	0.995611
4	2	1	0.798990	0.951019	0.844548		0.096802	0.984857
5	2	2	0.002735	0.009294	0.677493	0.096802		0.357095
6	2	3	0.387128	0.637219	0.995611	0.984857	0.357095	

	Degr. of - Freedom	F	p
COND	2	9.4671	0.000236

	COND	{1} - 7.6989	{2} - 7.6694	{3} - 8.5751
1	SPEEDACC BH tdev		0.991581	0.001321
2	SPEEDACC NITF tdev	0.991581		0.000916
3	SPEEDACC NEOF tdev	0.001321	0.000916	

Torque

% Maximum Voluntary Contraction

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.7429	0.394759
SIZE	2	5.3996	0.006661
MATERIAL*SIZE	2	1.4432	0.243311

	MATERIAL	SIZE	{1} - 18.484	{2} - 17.408	{3} - 20.400	{4} - 17.638	{5} - 18.940	{6} - 21.790
1	1	1		0.926208	0.519326	0.972945	0.998497	0.044461
2	1	2	0.926208		0.089405	0.999951	0.738894	0.002618
3	1	3	0.519326	0.089405		0.142013	0.775261	0.809570
4	2	1	0.972945	0.999951	0.142013		0.848200	0.004987
5	2	2	0.998497	0.738894	0.775261	0.848200		0.119589
6	2	3	0.044461	0.002618	0.809570	0.004987	0.119589	

	Degr. of - Freedom	F	p
COND	2	0.7846	0.460380

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	1.1284	0.295604
SIZES	2	1.5525	0.219135
MATERIAL*SIZES	2	0.7558	0.473530

	Degr. of - Freedom	F	p
COND	2	0.8712	0.423056

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.6964	0.409827
SIZES	2	0.2837	0.753864
MATERIAL*SIZES	2	0.4604	0.632987

	Degr. of - Freedom	F	p
COND	2	5.9312	0.004223

	COND	{1} - 27.907	{2} - 31.803	{3} - 32.640
1	TORQUE %MVC BH ECU		0.026372	0.005504
2	TORQUE %MVC NITF ECU	0.026372		0.836309
3	TORQUE %MVC NEOF ECU	0.005504	0.836309	

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	3.0368	0.090434
SIZE	2	2.1439	0.125058
MATERIAL*SIZE	2	0.8915	0.414795

	Degr. of - Freedom	F	p
COND	2	0.96641	0.385608

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.2570	0.615455
SIZES	2	2.3693	0.101228
MATERIAL*SIZES	2	0.4455	0.642374

	Degr. of - Freedom	F	p
COND	2	0.4658	0.629634

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	3.1147	0.086571
SIZES	2	2.7536	0.070806
MATERIAL*SIZES	2	0.6916	0.504248

	Degr. of - Freedom	F	p
COND	2	0.7559	0.473502

Peak torque

Concentric external rotation

	Degr. of - Freedom	F	p
MATERIAL	1	0.0983	0.756084
SIZE	2	4.9381	0.010343
MATERIAL*SIZE	2	1.3468	0.267830

	MATERIAL	SIZE	{1} - 8.7742	{2} - 8.8065	{3} - 8.0323	{4} - 8.3871	{5} - 8.7742	{6} - 8.2903
1	1	1		0.999997	0.097889	0.732645	1.000000	0.512972
2	1	2	0.999997		0.074750	0.661777	0.999997	0.440319
3	1	3	0.097889	0.074750		0.797633	0.097889	0.938068
4	2	1	0.732645	0.661777	0.797633		0.732645	0.999349
5	2	2	1.000000	0.999997	0.097889	0.732645		0.512972
6	2	3	0.512972	0.440319	0.938068	0.999349	0.512972	

	Degr. of - Freedom	F	p
COND	2	75.3682	0.00

	COND	{1} - 5.6774	{2} - 8.8065	{3} - 8.7742
1	TORQUE concEXT PEAK TORQUE BH		0.000117	0.000117
2	TORQUE concEXT PEAK TORQUE NITF	0.000117		0.993403
3	TORQUE concEXT PEAK TORQUE NEOF	0.000117	0.993403	

Concentric internal rotation

	Degr. of - Freedom	F	p
MATERIAL	1	0.3876	0.538258
SIZE	2	4.5404	0.014582
MATERIAL*SIZE	2	0.6439	0.528806

	MATERIAL	SIZE	{1} - 9.0000	{2} - 9.6452	{3} - 8.9677	{4} - 8.8387	{5} - 10.000	{6} - 9.2581
1	1	1		0.448137	0.999999	0.997335	0.062696	0.976594
2	1	2	0.448137		0.392827	0.209832	0.912027	0.877644
3	1	3	0.999999	0.392827		0.999124	0.049852	0.961111
4	2	1	0.997335	0.209832	0.999124		0.018712	0.836798
5	2	2	0.062696	0.912027	0.049852	0.018712		0.292724
6	2	3	0.976594	0.877644	0.961111	0.836798	0.292724	

	Degr. of - Freedom	F	p
COND	2	28.9073	0.000000

	COND	{1} - 6.7742	{2} - 9.6452	{3} - 10.000
1	TORQUE concINT PEAK TORQUE BH		0.000117	0.000117
2	TORQUE concINT PEAK TORQUE NITF	0.000117		0.727263
3	TORQUE concINT PEAK TORQUE NEOF	0.000117	0.727263	

Total Work

Concentric external rotation

	Degr. of - Freedom	F	p
MATERIAL	1	0.0835	0.774625
SIZE	2	1.5139	0.228327
MATERIAL*SIZE	2	0.5022	0.607706

	Degr. of - Freedom	F	p
COND	2	82.4707	0.00

	COND	{1} - 3.6129	{2} - 5.6774	{3} - 5.7419
1	TORQUE concEXT TOTAL WORK BH		0.000117	0.000117
2	TORQUE concEXT TOTAL WORK NITF	0.000117		0.937681
3	TORQUE concEXT TOTAL WORK NEOF	0.000117	0.937681	

Concentric internal rotation

	Degr. of - Freedom	F	p
MATERIAL	1	0.4548	0.505218
SIZE	2	3.9182	0.025156
MATERIAL*SIZE	2	0.4538	0.637341

	MATERIAL	SIZE	{1} - 5.4194	{2} - 6.0968	{3} - 5.7742	{4} - 5.7097	{5} - 6.1613	{6} - 5.7419
1	1	1		0.079057	0.700307	0.843921	0.041279	0.776906
2	1	2	0.079057		0.776906	0.617688	0.999838	0.700307
3	1	3	0.700307	0.776906		0.999838	0.617688	0.999995
4	2	1	0.843921	0.617688	0.999838		0.450010	0.999995
5	2	2	0.041279	0.999838	0.617688	0.450010		0.532985
6	2	3	0.776906	0.700307	0.999995	0.999995	0.532985	

	Degr. of - Freedom	F	P
COND	2	48.8080	0.0000000000003

	COND	{1} - 3.9355	{2} - 6.0968	{3} - 6.1613
1	TORQUE concINT TOTAL WORK BH		0.000117	0.000117
2	TORQUE concINT TOTAL WORK NITF	0.000117		0.965811
3	TORQUE concINT TOTAL WORK NEOF	0.000117	0.965811	

Average power

Concentric external rotation

	Degr. of - Freedom	F	p
MATERIAL	1	0.4726	0.497079
SIZES	2	4.1480	0.020543
MATERIAL*SIZES	2	0.0082	0.991831

	MATERIAL	SIZES	{1} - 6.2581	{2} - 6.4839	{3} - 5.9677	{4} - 6.3548	{5} - 6.5806	{6} - 6.0968
1	1	1		0.880268	0.719798	0.997037	0.621929	0.969201
2	1	2	0.880268		0.137605	0.988588	0.997037	0.422819
3	1	3	0.719798	0.137605		0.422819	0.045605	0.988588
4	2	1	0.997037	0.988588	0.422819		0.880268	0.807776
5	2	2	0.621929	0.997037	0.045605	0.880268		0.189751
6	2	3	0.969201	0.422819	0.988588	0.807776	0.189751	

	Degr. of - Freedom	F	p
COND	2	94.7754	0.00

	COND	{1} - 4.1290	{2} - 6.4839	{3} - 6.5806
1	TORQUE concEXT AVG PWR BH		0.000117	0.000117
2	TORQUE concEXT AVG PWR NITF	0.000117		0.881147
3	TORQUE concEXT AVG PWR NEOF	0.000117	0.881147	

Concentric internal rotation

	Degr. of - Freedom	F	p
MATERIAL	1	0.1542	0.697284
SIZES	2	7.4446	0.001294
MATERIAL*SIZES	2	0.1676	0.846088

	MATERIAL	SIZES	{1} - 6.5484	{2} - 7.3226	{3} - 6.6452	{4} - 6.7419	{5} - 7.3548	{6} - 6.6452
1	1	1		0.037498	0.998938	0.972497	0.026739	0.998938
2	1	2	0.037498		0.095742	0.213394	0.999996	0.095742
3	1	3	0.998938	0.095742		0.998938	0.071053	1.000000
4	2	1	0.972497	0.213394	0.998938		0.166048	0.998938
5	2	2	0.026739	0.999996	0.071053	0.166048		0.071053
6	2	3	0.998938	0.095742	1.000000	0.998938	0.071053	

	Degr. of - Freedom	F	p
COND	2	65.0000	0.000000000000001

	COND	{1} - 4.5161	{2} - 7.3226	{3} - 7.3548
1	TORQUE concINT AVG PWR BH		0.000117	0.000117
2	TORQUE concINT AVG PWR NITF	0.000117		0.993081
3	TORQUE concINT AVG PWR NEOF	0.000117	0.993081	

Maximum pulling force

% Maximum Voluntary Contraction

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	1.0257	0.318313
SIZES	2	0.4283	0.653360
MATERIAL*SIZES	2	0.8832	0.418162

	Degr. of - Freedom	F	p
COND	2	1.1122	0.334740

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	3.7724	0.060425
SIZE	2	0.0216	0.978604
MATERIAL*SIZE	2	0.7938	0.456289

	Degr. of - Freedom	F	p
COND	2	1.6214	0.205174

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	1.08083	0.305850
SIZE	2	0.02145	0.978781
MATERIAL*SIZE	2	4.43733	0.015441

	MATERIAL	SIZE	{1} - 24.120	{2} - 22.546	{3} - 26.666	{4} - 23.536	{5} - 25.174	{6} - 21.441
1	1	1		0.958981	0.751392	0.999628	0.993154	0.709020
2	1	2	0.958981		0.252341	0.994921	0.725766	0.991435
3	1	3	0.751392	0.252341		0.555972	0.967322	0.071787
4	2	1	0.999628	0.994921	0.555972		0.951453	0.872385
5	2	2	0.993154	0.725766	0.967322	0.951453		0.357707
6	2	3	0.709020	0.991435	0.071787	0.872385	0.357707	

	SS	Degr. of - Freedom	MS	F	p
COND	180.65	2	90.32	2.40890	0.097550

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	5.0369	0.031432
SIZES	2	0.4505	0.639205
MATERIAL*SIZES	2	4.4981	0.014633

	MATERIAL	SIZES	{1} - 30.378	{2} - 30.078	{3} - 34.811	{4} - 28.988	{5} - 31.032	{6} - 27.233
1	1	1		0.999992	0.283296	0.984812	0.999611	0.657037
2	1	2	0.999992		0.217780	0.995066	0.997387	0.745157
3	1	3	0.283296	0.217780		0.069438	0.461306	0.006701
4	2	1	0.984812	0.995066	0.069438		0.921711	0.957984
5	2	2	0.999611	0.997387	0.461306	0.921711		0.455177
6	2	3	0.657037	0.745157	0.006701	0.957984	0.455177	

	Degr. of - Freedom	F	p
COND	2	1.3602	0.263513

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.5750	0.453499
SIZE	2	0.0632	0.938789
MATERIAL*SIZE	2	1.2444	0.294604

	Degr. of - Freedom	F	p
COND	2	0.4152	0.661864

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	2.5326	0.120773
SIZE	2	0.6109	0.545797
MATERIAL*SIZE	2	3.7246	0.029177

	MATERIAL	SIZE	{1} - 46.269	{2} - 42.979	{3} - 45.561	{4} - 46.565	{5} - 49.793	{6} - 44.871
1	1	1		0.629271	0.999473	0.999993	0.557442	0.985531
2	1	2	0.629271		0.824703	0.538657	0.022943	0.946454
3	1	3	0.999473	0.824703		0.996928	0.351673	0.999532
4	2	1	0.999993	0.538657	0.996928		0.647825	0.966301
5	2	2	0.557442	0.022943	0.351673	0.647825		0.196782
6	2	3	0.985531	0.946454	0.999532	0.966301	0.196782	

	Degr. of - Freedom	F	p
COND	2	4.3914	0.016082

	COND	{1} - 45.585	{2} - 42.979	{3} - 49.793
1	MAX F %MVC BH MAXPULL FCR		0.503455	0.172889
2	MAX F %MVC NITF MAXPULL FCR	0.503455		0.012513
3	MAX F %MVC NEOF MAXPULL FCR	0.172889	0.012513	

Maximum pushing force

% Maximum Voluntary Contraction

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	4.3774	0.043958
SIZES	2	0.4293	0.652689
MATERIAL*SIZES	2	0.5322	0.589721

	MATERIAL	SIZES	{1} - 23.765	{2} - 23.558	{3} - 23.361	{4} - 22.385	{5} - 20.783	{6} - 22.635
1	1	1		0.999992	0.999776	0.928346	0.310699	0.968750
2	1	2	0.999992		0.999994	0.963326	0.390597	0.987237
3	1	3	0.999776	0.999994		0.983584	0.474280	0.995834
4	2	1	0.928346	0.963326	0.983584		0.872792	0.999979
5	2	2	0.310699	0.390597	0.474280	0.872792		0.788982
6	2	3	0.968750	0.987237	0.995834	0.999979	0.788982	

	Degr. of - Freedom	F	p
COND	2	1.5137	0.227406

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	1.6759	0.204198
SIZES	2	0.2443	0.783918
MATERIAL*SIZES	2	0.7082	0.496129

	Degr. of - Freedom	F	p
COND	2	0.0184	0.981775

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.2379	0.628843
SIZES	2	0.2860	0.752181
MATERIAL*SIZES	2	0.2051	0.815036

	Degr. of - Freedom	F	p
COND	2	4.3274	0.017020

	COND	{1} - 56.986	{2} - 50.161	{3} - 51.915
1	MAX F %MVC BH MAXPUSH ECU		0.016628	0.096502
2	MAX F %MVC NITF MAXPUSH ECU	0.016628		0.747973
3	MAX F %MVC NEOF MAXPUSH ECU	0.096502	0.747973	

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.67979	0.415406
SIZES	2	0.80251	0.452400
MATERIAL*SIZES	2	0.21623	0.806099

	Degr. of - Freedom	F	p
COND	2	0.17802	0.837316

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.03531	0.852070
SIZES	2	0.32439	0.724078
MATERIAL*SIZES	2	0.02159	0.978652

	Degr. of - Freedom	F	p
COND	2	0.52839	0.591955

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	3.2760	0.079148
SIZES	2	0.2823	0.754959
MATERIAL*SIZES	2	0.2853	0.752692

	Degr. of - Freedom	F	p
COND	2	70.4150	0.0000000002

	COND	{1} - 16.744	{2} - 18.755	{3} - 49.793
1	MAX F %MVC BH MAXPUSH FCR		0.796371	0.000112
2	MAX F %MVC NITF MAXPUSH FCR	0.796371		0.000112
3	MAX F %MVC NEOF MAXPULL FCR	0.000112	0.000112	

Maximum pulling force (N)

	Degr. of - Freedom	F	p
MATERIAL	1	0.4162	0.523182
SIZES	2	1.3233	0.273032
MATERIAL*SIZES	2	0.2515	0.778369

	Degr. of - Freedom	F	p
COND	2	0.3913	0.677719

Maximum pushing force (N)

	Degr. of - Freedom	F	p
MATERIAL	1	0.1781	0.675646
SIZES	2	0.4103	0.665066
MATERIAL*SIZES	2	3.0889	0.051997

	Degr. of - Freedom	F	p
COND	2	2.9634	0.058351

Precision of force: TREND

Pulling force

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	6.631171	0.014544
SIZES	2	0.052041	0.949328
MATERIAL*SIZES	2	1.771271	0.177875

	MATERIAL	SIZES	{1} - 3.7431	{2} - .36550	{3} - -4.791	{4} - -10.05	{5} - -7.692	{6} - -4.700
1	1	1		0.987200	0.583540	0.103808	0.260195	0.594853
2	1	2	0.987200		0.921724	0.360590	0.642140	0.927087
3	1	3	0.583540	0.921724		0.915306	0.993657	1.000000
4	2	1	0.103808	0.360590	0.915306		0.997619	0.909430
5	2	2	0.260195	0.642140	0.993657	0.997619		0.992654
6	2	3	0.594853	0.927087	1.000000	0.909430	0.992654	

	Degr. of - Freedom	F	p
COND	2	1.474718	0.236069

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	2.324352	0.136612
SIZES	2	1.529063	0.224097
MATERIAL*SIZES	2	3.764261	0.028153

	MATERIAL	SIZES	{1} - -2.420	{2} - 13.153	{3} - -6.712	{4} - -4.720	{5} - -4.809	{6} - -1.226
1	1	1		0.129985	0.981709	0.999055	0.998863	0.999964
2	1	2	0.129985		0.022775	0.053915	0.051967	0.194340
3	1	3	0.981709	0.022775		0.999554	0.999643	0.947398
4	2	1	0.999055	0.053915	0.999554		1.000000	0.992845
5	2	2	0.998863	0.051967	0.999643	1.000000		0.991954
6	2	3	0.999964	0.194340	0.947398	0.992845	0.991954	

	Degr. of - Freedom	F	p
COND	2	3.072161	0.052802

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.172029	0.680920
SIZES	2	0.179784	0.835846
MATERIAL*SIZES	2	1.610248	0.207364

	Degr. of - Freedom	F	p
COND	2	0.717122	0.491809

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.659111	0.422522
SIZES	2	2.448621	0.093999
MATERIAL*SIZES	2	0.644779	0.527956

	Degr. of - Freedom	F	p
COND	2	0.663666	0.518264

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	1.989344	0.167493
SIZES	2	0.402704	0.670094
MATERIAL*SIZES	2	0.784149	0.460592

	Degr. of - Freedom	F	p
COND	2	0.436283	0.648231

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.824127	0.370366
SIZES	2	0.444338	0.643097
MATERIAL*SIZES	2	0.999256	0.373494

	Degr. of - Freedom	F	p
COND	2	0.580712	0.562250

Pushing Force

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.964591	0.332970
SIZES	2	0.225977	0.798333
MATERIAL*SIZES	2	0.054579	0.946925

	Degr. of - Freedom	F	p
COND	2	0.790921	0.457554

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	0.200664	0.657027
SIZES	2	0.112023	0.894188
MATERIAL*SIZES	2	0.112877	0.893428

	Degr. of - Freedom	F	p
COND	2	0.148334	0.862422

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.529097	0.471966
SIZES	2	0.852433	0.430882
MATERIAL*SIZES	2	4.756504	0.011656

	MATERIAL	SIZES	{1} - 5.6123	{2} - 2.5424	{3} - -4.057	{4} - -14.02	{5} - .63957	{6} - 8.4736
1	1	1		0.998411	0.779213	0.097585	0.984373	0.998875
2	1	2	0.998411		0.946905	0.232501	0.999854	0.966092
3	1	3	0.779213	0.946905		0.756609	0.987952	0.539096
4	2	1	0.097585	0.232501	0.756609		0.361712	0.037336
5	2	2	0.984373	0.999854	0.987952	0.361712		0.895183
6	2	3	0.998875	0.966092	0.539096	0.037336	0.895183	

	Degr. of - Freedom	F	p
COND	2	0.391092	0.677830

Extensor Carpi Radialis

	Degr. Of – Freedom	F	p
MATERIAL	1	0.269645	0.606934
SIZE	2	1.235819	0.297040
MATERIAL*SIZE	2	1.888778	0.159107

	Degr. of - Freedom	F	p
COND	2	0.011242	0.988823

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.896397	0.350430
SIZES	2	0.157840	0.854298
MATERIAL*SIZES	2	0.330859	0.719457

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	1.351198	0.253163
SIZES	2	2.045304	0.137223

	Degr. of - Freedom	F	p
COND	2	0.670747	0.514677
MATERIAL*SIZES	2	0.979820	0.380615

	Degr. of - Freedom	F	p
COND	2	0.514976	0.599827

Precision of force: DEVIATION FROM TREND

Pulling force

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.4246	0.519015
SIZES	2	2.8914	0.062351
MATERIAL*SIZES	2	0.2477	0.781289

	Degr. of - Freedom	F	p
COND	2	0.0430	0.957964

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	2.1681	0.150095
SIZES	2	2.9935	0.056755
MATERIAL*SIZES	2	0.3015	0.740656

	Degr. of - Freedom	F	P
COND	2	0.6039	0.549600

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.50776	0.480971
SIZES	2	0.06682	0.935429
MATERIAL*SIZES	2	0.10292	0.902341

	Degr. of - Freedom	F	p
COND	2	0.58567	0.559515

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	1.45254	0.236442
SIZES	2	0.81460	0.447092
MATERIAL*SIZES	2	0.33268	0.718156

	Degr. of - Freedom	F	p
COND	2	1.14613	0.323927

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.7853	0.381757
SIZES	2	3.9686	0.023435
MATERIAL*SIZES	2	0.0381	0.962594

	MATERIAL	SIZES	{1} - 19.571	{2} - 16.438	{3} - 20.403	{4} - 20.096	{5} - 17.220	{6} - 21.777
1	1	1		0.723458	0.999057	0.999906	0.897264	0.919682
2	1	2	0.723458		0.485840	0.574612	0.999325	0.172458
3	1	3	0.999057	0.485840		0.999993	0.709880	0.989533
4	2	1	0.999906	0.574612	0.999993		0.789208	0.974118
5	2	2	0.897264	0.999325	0.709880	0.789208		0.328647
6	2	3	0.919682	0.172458	0.989533	0.974118	0.328647	

	Degr. of - Freedom	F	p
COND	2	0.34736	0.707798

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.01181	0.914108
SIZES	2	2.72940	0.072412
MATERIAL*SIZES	2	0.34311	0.710782

	Degr. of - Freedom	F	p
COND	2	3.05748	0.053518

Pushing force

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.55773	0.460310
SIZES	2	2.80549	0.067492
MATERIAL*SIZES	2	3.33402	0.041564

	MATERIAL	SIZES	{1} - 14.935	{2} - 13.735	{3} - 21.009	{4} - 17.799	{5} - 12.548	{6} - 15.238
1	1	1		0.995821	0.119735	0.830331	0.913543	0.999995
2	1	2	0.995821		0.034573	0.525384	0.996016	0.987991
3	1	3	0.119735	0.034573		0.752187	0.008284	0.157709
4	2	1	0.830331	0.525384	0.752187		0.242729	0.886870
5	2	2	0.913543	0.996016	0.008284	0.242729		0.864184
6	2	3	0.999995	0.987991	0.157709	0.886870	0.864184	

	Degr. of - Freedom	F	p
COND	2	0.20532	0.814892

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	3.12784	0.085937
SIZES	2	2.75118	0.070968
MATERIAL*SIZES	2	0.65121	0.524637

	Degr. of - Freedom	F	p
COND	2	2.32610	0.105401

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.39643	0.533145
SIZES	2	1.99245	0.144243
MATERIAL*SIZES	2	1.32947	0.271407

	Degr. of - Freedom	F	p
COND	2	0.05695	0.944688

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.48947	0.488923
SIZES	2	2.22094	0.116320
MATERIAL*SIZES	2	0.70502	0.497675

	Degr. of - Freedom	F	p
COND	2	1.73516	0.184090

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	3.72705	0.061912
SIZES	2	3.24370	0.045132
MATERIAL*SIZES	2	1.57609	0.214242

	MATERIAL	SIZES	{1} - 11.304	{2} - 11.666	{3} - 13.923	{4} - 14.650	{5} - 11.572	{6} - 18.278
1	1	1		0.999963	0.720980	0.471985	0.999992	0.004780
2	1	2	0.999963		0.828016	0.597277	1.000000	0.008699
3	1	3	0.720980	0.828016		0.998820	0.802588	0.191099
4	2	1	0.471985	0.597277	0.998820		0.564792	0.379768
5	2	2	0.999992	1.000000	0.802588	0.564792		0.007486
6	2	3	0.004780	0.008699	0.191099	0.379768	0.007486	

	Degr. of - Freedom	F	p
COND	2	26.21929	0.00000000362

	COND	{1} - 9.4351	{2} - 36.738	{3} - 11.572
1	30%MVC DEV BH PUSH FCU		0.000112	0.866959
2	30%MVC DEV NITF PUSH ECU	0.000112		0.000112
3	30%MVC DEV NEOF PUSH FCU	0.866959	0.000112	

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.20114	0.656647
SIZES	2	1.53057	0.223775
MATERIAL*SIZES	2	1.70648	0.189183

	Degr. of - Freedom	F	p
COND	2	0.43115	0.651528

Precision of force: TREND

Pulling force (N)

	Degr. of - Freedom	F	p
MATERIAL	1	0.400706	0.530960
SIZES	2	1.387386	0.256705
MATERIAL*SIZES	2	0.478660	0.621685

	Degr. of - Freedom	F	p
COND	2	2.018873	0.140689

Pushing force (N)

	Degr. of - Freedom	F	p
MATERIAL	1	0.00321	0.955164
SIZES	2	1.55964	0.217637
MATERIAL*SIZES	2	3.37925	0.039888

	MATERIAL	SIZES	{1} - -8.831	{2} - -9.329	{3} - -18.50	{4} - -18.86	{5} - -7.614	{6} - -9.700
1	1	1		0.999999	0.429466	0.388686	0.999907	0.999982
2	1	2	0.999999		0.489570	0.446761	0.999498	1.000000
3	1	3	0.429466	0.489570		1.000000	0.297234	0.535523
4	2	1	0.388686	0.446761	1.000000		0.263850	0.491731
5	2	2	0.999907	0.999498	0.297234	0.263850		0.998635

6	2	3	0.999982	1.000000	0.535523	0.491731	0.998635	

	Degr. of - Freedom	F	p
COND	2	0.117447	0.889367

Precision of force: DEVIATION FROM TREND

Pulling force (N)

	Degr. of - Freedom	F	p
MATERIAL	1	0.9987	0.324676
SIZES	2	2.8503	0.064757
MATERIAL*SIZES	2	2.6815	0.075700

	Degr. of - Freedom	F	p
COND	2	2.6131	0.080660

	Degr. of - Freedom	F	p
COND	2	2.2064	0.117917

Pushing force (N)

	Degr. of - Freedom	F	p
MATERIAL	1	1.6638	0.205794
SIZES	2	1.9104	0.155887
MATERIAL*SIZES	2	1.2938	0.280889

Tactility

Flexor Digitorum Superficialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.0330	0.857026
SIZE	2	2.2832	0.109722
MASS	2	8.2991	0.000596
MATERIAL*SIZE	2	0.4316	0.651216
MATERIAL*MASS	2	0.5002	0.608602
SIZE*MASS	4	1.1024	0.358064
MATERIAL*SIZE*MASS	4	3.6842	0.007003

	MATERIAL	SIZE	MASS	{1} - 2.1477	{2} - 2.1928	{3} - 2.2525	{4} - 2.0964	{5} - 2.0682	{6} - 2.3341
1	1	1	1		1.000000	0.995663	1.000000	0.999868	0.534212
2	1	1	2	1.000000		0.999998	0.998406	0.972474	0.915319
3	1	1	3	0.995663	0.999998		0.822815	0.555318	0.999815
4	1	2	1	1.000000	0.998406	0.822815		1.000000	0.125060
5	1	2	2	0.999868	0.972474	0.555318	1.000000		0.039578
6	1	2	3	0.534212	0.915319	0.999815	0.125060	0.039578	
7	1	3	1	0.085604	0.371816	0.907727	0.007914	0.001631	0.999997
8	1	3	2	0.062719	0.303563	0.862740	0.005259	0.001038	0.999983
9	1	3	3	0.421768	0.850147	0.999027	0.082035	0.023817	1.000000
10	2	1	1	1.000000	0.999991	0.970158	1.000000	0.999998	0.329359
11	2	1	2	0.899608	0.502538	0.080539	0.998964	0.999993	0.001323
12	2	1	3	0.882292	0.996700	1.000000	0.408897	0.181937	1.000000
13	2	2	1	1.000000	1.000000	0.999991	0.999295	0.983276	0.882361
14	2	2	2	0.978192	0.999921	1.000000	0.671793	0.384285	0.999993
15	2	2	3	0.802324	0.989271	1.000000	0.305538	0.122434	1.000000
16	2	3	1	0.993649	0.999995	1.000000	0.794443	0.518172	0.999899
17	2	3	2	0.985340	0.999967	1.000000	0.716986	0.429468	0.999981
18	2	3	3	0.008826	0.072363	0.475299	0.000467	0.000098	0.992112

	{13} – 2.1867	{14} - 2.2694	{15} - 2.3064	{16} - 2.2561	{17} - 2.2648	{18} - 2.4446
1	1.000000	0.978192	0.802324	0.993649	0.985340	0.008826
2	1.000000	0.999921	0.989271	0.999995	0.999967	0.072363
3	0.999991	1.000000	1.000000	1.000000	1.000000	0.475299
4	0.999295	0.671793	0.305538	0.794443	0.716986	0.000467
5	0.983276	0.384285	0.122434	0.518172	0.429468	0.000098
6	0.882361	0.999993	1.000000	0.999899	0.999981	0.992112
7	0.317147	0.969527	0.999420	0.924894	0.957224	1.000000
8	0.254887	0.947517	0.998358	0.885118	0.929503	1.000000
9	0.804609	0.999934	1.000000	0.999411	0.999850	0.997655
10	0.999998	0.909133	0.605043	0.961135	0.930791	0.002818
11	0.565588	0.039336	0.006354	0.069694	0.048266	0.000036
12	0.993606	1.000000	1.000000	1.000000	1.000000	0.869513
13		0.999777	0.981529	0.999981	0.999899	0.056235
14	0.999777		1.000000	1.000000	1.000000	0.650179
15	0.981529	1.000000		1.000000	1.000000	0.929779
16	0.999981	1.000000	1.000000		1.000000	0.512054
17	0.999899	1.000000	1.000000	1.000000		0.602584
18	0.056235	0.650179	0.929779	0.512054	0.602584	

	{7} - 2.3954	{8} - 2.4030	{9} - 2.3452	{10} - 2.1269	{11} - 2.0033	{12} - 2.2952
1	0.085604	0.062719	0.421768	1.000000	0.899608	0.882292
2	0.371816	0.303563	0.850147	0.999991	0.502538	0.996700
3	0.907727	0.862740	0.999027	0.970158	0.080539	1.000000
4	0.007914	0.005259	0.082035	1.000000	0.998964	0.408897
5	0.001631	0.001038	0.023817	0.999998	0.999993	0.181937
6	0.999997	0.999983	1.000000	0.329359	0.001323	1.000000
7		1.000000	1.000000	0.035270	0.000056	0.997428
8	1.000000		0.999999	0.024747	0.000047	0.993954
9	1.000000	0.999999		0.240139	0.000686	1.000000
10	0.035270	0.024747	0.240139		0.974766	0.717777
11	0.000056	0.000047	0.000686	0.974766		0.011471
12	0.997428	0.993954	1.000000	0.717777	0.011471	
13	0.317147	0.254887	0.804609	0.999998	0.565588	0.993606
14	0.969527	0.947517	0.999934	0.909133	0.039336	1.000000
15	0.999420	0.998358	1.000000	0.605043	0.006354	1.000000
16	0.924894	0.885118	0.999411	0.961135	0.069694	1.000000
17	0.957224	0.929503	0.999850	0.930791	0.048266	1.000000
18	1.000000	1.000000	0.997655	0.002818	0.000036	0.869513

	Degr. of - Freedom	F	P
COND	2	0.2357	0.790658
MASS	2	14.3869	0.000006
COND*MASS	4	7.2639	0.000025

	COND	MASS	{1} - 1.9582	{2} - 2.0378	{3} - 2.6001	{4} - 2.0964
1	1	1		0.988994	0.000010	0.762203
2	1	2	0.988994		0.000010	0.998660
3	1	3	0.000010	0.000010		0.000010
4	2	1	0.762203	0.998660	0.000010	
5	2	2	0.921858	0.999991	0.000010	0.999995
6	2	3	0.000209	0.009953	0.034432	0.093300
7	3	1	0.124566	0.678786	0.000028	0.975204
8	3	2	0.005108	0.112929	0.002016	0.475368
9	3	3	0.000838	0.031080	0.011192	0.210359

{5} - 2.0682	{6} - 2.3341	{7} - 2.1867	{8} - 2.2694	{9} - 2.3064
0.921858	0.000209	0.124566	0.005108	0.000838
0.999991	0.009953	0.678786	0.112929	0.031080
0.000010	0.034432	0.000028	0.002016	0.011192
0.999995	0.093300	0.975204	0.475368	0.210359
	0.034484	0.883700	0.262463	0.091568
0.034484		0.691375	0.997312	0.999995
0.883700	0.691375		0.985773	0.877845
0.262463	0.997312	0.985773		0.999957
0.091568	0.999995	0.877845	0.999957	

Flexor Pollicus Longus

	Degr. of - Freedom	F	p
MATERIAL	1	0.0053	0.942180
SIZE	2	3.1396	0.049636
MASS	2	26.4894	0.000000003
MATERIAL*SIZE	2	2.6583	0.077346
MATERIAL*MASS	2	1.0807	0.345121
SIZE*MASS	4	2.6413	0.036434
MATERIAL*SIZE*MASS	4	0.6829	0.604967

	{1} - 2.5804	{2} - 2.7723	{3} - 3.2402	{4} - 2.6246	{5} - 2.7807	{6} - 3.4011
1		0.978909	0.000039	1.000000	0.967860	0.000036
2	0.978909		0.009330	0.998921	1.000000	0.000049
3	0.000039	0.009330		0.000060	0.012277	0.996929
4	1.000000	0.998921	0.000060		0.997856	0.000036
5	0.967860	1.000000	0.012277	0.997856		0.000055
6	0.000036	0.000049	0.996929	0.000036	0.000055	
7	0.000036	0.002221	1.000000	0.000039	0.003014	0.999935
8	0.491341	0.999981	0.184333	0.769516	0.999994	0.001528
9	0.000036	0.000036	0.000410	0.000036	0.000036	0.082332
10	0.999188	1.000000	0.001772	0.999995	1.000000	0.000037
11	0.063664	0.947354	0.773267	0.181704	0.963693	0.043328
12	0.000036	0.000048	0.996583	0.000036	0.000054	1.000000
13	0.999997	0.999998	0.000291	1.000000	0.999991	0.000036
14	0.907229	1.000000	0.027215	0.987797	1.000000	0.000101
15	0.000059	0.034655	1.000000	0.000204	0.044003	0.962754
16	0.016489	0.763658	0.951089	0.059241	0.808549	0.141486
17	0.780764	1.000000	0.061384	0.948235	1.000000	0.000268
18	0.000036	0.000036	0.059175	0.000036	0.000036	0.831562
	{7} - 3.2814	**{8} - 2.8818**	**{9} - 3.7943**	**{10} - 2.7248**	**{11} - 2.9836**	**{12} - 3.4025**
1	0.000036	0.491341	0.000036	0.999188	0.063664	0.000036
2	0.002221	0.999981	0.000036	1.000000	0.947354	0.000048
3	1.000000	0.184333	0.000410	0.001772	0.773267	0.996583
4	0.000039	0.769516	0.000036	0.999995	0.181704	0.000036
5	0.003014	0.999994	0.000036	1.000000	0.963693	0.000054
6	0.999935	0.001528	0.082332	0.000037	0.043328	1.000000
7		0.069861	0.001937	0.000374	0.514592	0.999923
8	0.069861		0.000036	0.997726	0.999994	0.001448

9	0.001937	0.000036		0.000036	0.000036	0.085409
10	0.000374	0.997726	0.000036		0.760527	0.000037
11	0.514592	0.999994	0.000036	0.760527		0.041594
12	0.999923	0.001448	0.085409	0.000037	0.041594	
13	0.000077	0.960229	0.000036	1.000000	0.456126	0.000036
14	0.007388	1.000000	0.000036	1.000000	0.990859	0.000097
15	1.000000	0.399516	0.000095	0.007937	0.941428	0.960196
16	0.802865	0.998820	0.000036	0.463280	1.000000	0.136890
17	0.018788	1.000000	0.000036	0.999978	0.998883	0.000254
18	0.161036	0.000036	0.998876	0.000036	0.000038	0.838359
	{13} - 2.6769	**{14} - 2.8065**	**{15} - 3.1976**	**{16} - 3.0305**	**{17} - 2.8355**	**{18} - 3.6461**
1	0.999997	0.907229	0.000059	0.016489	0.780764	0.000036
2	0.999998	1.000000	0.034655	0.763658	1.000000	0.000036
3	0.000291	0.027215	1.000000	0.951089	0.061384	0.059175
4	1.000000	0.987797	0.000204	0.059241	0.948235	0.000036
5	0.999991	1.000000	0.044003	0.808549	1.000000	0.000036
6	0.000036	0.000101	0.962754	0.141486	0.000268	0.831562
7	0.000077	0.007388	1.000000	0.802865	0.018788	0.161036
8	0.960229	1.000000	0.399516	0.998820	1.000000	0.000036
9	0.000036	0.000036	0.000095	0.000036	0.000036	0.998876
10	1.000000	1.000000	0.007937	0.463280	0.999978	0.000036
11	0.456126	0.990859	0.941428	1.000000	0.998883	0.000038
12	0.000036	0.000097	0.960196	0.136890	0.000254	0.838359
13		0.999802	0.001449	0.203208	0.997398	0.000036
14	0.999802		0.086927	0.913933	1.000000	0.000036
15	0.001449	0.086927		0.995242	0.170511	0.017312
16	0.203208	0.913933	0.995242		0.975242	0.000060
17	0.997398	1.000000	0.170511	0.975242		0.000036
18	0.000036	0.000036	0.017312	0.000060	0.000036	

	Degr. of - Freedom	F	p
COND	2	0.7969	0.454868
MASS	2	34.4731	0.000000
COND*MASS	4	6.0693	0.000159

	COND	MASS	{1} - 2.5113	{2} - 2.7559	{3} - 3.7915	{4} - 2.6246
1	1	1		0.509432	0.000010	0.990090
2	1	2	0.509432		0.000010	0.974484
3	1	3	0.000010	0.000010		0.000010
4	2	1	0.990090	0.974484	0.000010	
5	2	2	0.369184	1.000000	0.000010	0.929466
6	2	3	0.000010	0.000012	0.029811	0.000010
7	3	1	0.903338	0.999204	0.000010	0.999964
8	3	2	0.245554	0.999972	0.000010	0.844810
9	3	3	0.000011	0.006723	0.000032	0.000064

{5} - 2.7807	{6} - 3.4011	{7} - 2.6769	{8} - 2.8065	{9} - 3.1976
0.369184	0.000010	0.903338	0.245554	0.000011
1.000000	0.000012	0.999204	0.999972	0.006723
0.000010	0.029811	0.000010	0.000010	0.000032
0.929466	0.000010	0.999964	0.844810	0.000064
	0.000017	0.994469	1.000000	0.014244
0.000017		0.000010	0.000031	0.744492
0.994469	0.000010		0.976384	0.000465
1.000000	0.000031	0.976384		0.029301
0.014244	0.744492	0.000465	0.029301	

Extensor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	2.5152	0.122009
SIZE	2	3.4534	0.037290
MASS	2	45.0913	0.0000000000003
MATERIAL*SIZE	2	0.9433	0.394363
MATERIAL*MASS	2	1.7968	0.173611
SIZE*MASS	4	0.5186	0.722176
MATERIAL*SIZE*MASS	4	2.2163	0.070444

	MATERIAL	SIZE	MASS	{1} - 7.6616	{2} - 8.7188	{3} - 10.861	{4} - 7.1865	{5} - 8.5044	{6} - 10.533
1	1	1	1		0.902052	0.000036	0.999993	0.988118	0.000057
2	1	1	2	0.902052		0.011562	0.317517	1.000000	0.087817
3	1	1	3	0.000036	0.011562		0.000036	0.002363	1.000000
4	1	2	1	0.999993	0.317517	0.000036		0.606622	0.000036
5	1	2	2	0.988118	1.000000	0.002363	0.606622		0.024727
6	1	2	3	0.000057	0.087817	1.000000	0.000036	0.024727	
7	1	3	1	0.378694	0.999999	0.144353	0.038550	0.999557	0.506349
8	1	3	2	0.960863	1.000000	0.005361	0.455724	1.000000	0.047939
9	1	3	3	0.000036	0.000036	0.312802	0.000036	0.000036	0.066716
10	2	1	1	1.000000	0.998993	0.000071	0.986973	0.999995	0.000770
11	2	1	2	0.653417	1.000000	0.049790	0.116882	0.999998	0.256587
12	2	1	3	0.000036	0.000048	0.994751	0.000036	0.000037	0.858146
13	2	2	1	1.000000	0.620293	0.000036	1.000000	0.873040	0.000037
14	2	2	2	0.990459	1.000000	0.002067	0.630485	1.000000	0.022143
15	2	2	3	0.000074	0.118152	1.000000	0.000036	0.035420	1.000000
16	2	3	1	0.529648	1.000000	0.081915	0.073322	0.999967	0.357773
17	2	3	2	0.000036	0.005297	1.000000	0.000036	0.000990	0.999998
18	2	3	3	0.000036	0.000036	0.007092	0.000036	0.000036	0.000543

	{7} - 9.1443	{8} - 8.6115	{9} - 12.397	{10} - 8.0367	{11} - 8.9458	{12} - 11.643
1	0.378694	0.960863	0.000036	1.000000	0.653417	0.000036
2	0.999999	1.000000	0.000036	0.998993	1.000000	0.000048
3	0.144353	0.005361	0.312802	0.000071	0.049790	0.994751
4	0.038550	0.455724	0.000036	0.986973	0.116882	0.000036
5	0.999557	1.000000	0.000036	0.999995	0.999998	0.000037
6	0.506349	0.047939	0.066716	0.000770	0.256587	0.858146
7		0.999964	0.000036	0.860793	1.000000	0.000752
8	0.999964		0.000036	0.999895	1.000000	0.000040
9	0.000036	0.000036		0.000036	0.000036	0.996603
10	0.860793	0.999895	0.000036		0.974224	0.000036

11	1.000000	1.000000	0.000036	0.974224		0.000155
12	0.000752	0.000040	0.996603	0.000036	0.000155	
13	0.132873	0.761707	0.000036	0.999668	0.314080	0.000036
14	0.999377	1.000000	0.000036	0.999997	0.999996	0.000037
15	0.587118	0.066617	0.048015	0.001223	0.320041	0.800298
16	1.000000	0.999999	0.000036	0.939586	1.000000	0.000306
17	0.082611	0.002330	0.452459	0.000047	0.025472	0.999140
18	0.000036	0.000036	0.999122	0.000036	0.000036	0.450956

	{13} - 7.4107	{14} - 8.4873	{15} - 10.476	{16} - 9.0338	{17} - 10.970	{18} - 13.072
1	1.000000	0.990459	0.000074	0.529648	0.000036	0.000036
2	0.620293	1.000000	0.118152	1.000000	0.005297	0.000036
3	0.000036	0.002067	1.000000	0.081915	1.000000	0.007092
4	1.000000	0.630485	0.000036	0.073322	0.000036	0.000036
5	0.873040	1.000000	0.035420	0.999967	0.000990	0.000036
6	0.000037	0.022143	1.000000	0.357773	0.999998	0.000543
7	0.132873	0.999377	0.587118	1.000000	0.082611	0.000036
8	0.761707	1.000000	0.066617	0.999999	0.002330	0.000036
9	0.000036	0.000036	0.048015	0.000036	0.452459	0.999122
10	0.999668	0.999997	0.001223	0.939586	0.000047	0.000036
11	0.314080	0.999996	0.320041	1.000000	0.025472	0.000036
12	0.000036	0.000037	0.800298	0.000306	0.999140	0.450956
13		0.887162	0.000039	0.220855	0.000036	0.000036
14	0.887162		0.031868	0.999948	0.000862	0.000036
15	0.000039	0.031868		0.432254	0.999988	0.000342
16	0.220855	0.999948	0.432254		0.043964	0.000036
17	0.000036	0.000862	0.999988	0.043964		0.015211
18	0.000036	0.000036	0.000342	0.000036	0.015211	

	Degr. of - Freedom	F	p
COND	2	8.7061	0.000430
MASS	2	40.9353	0.000000000002
COND*MASS	4	9.5084	0.000001

	COND	MASS	{1} - 7.6184	{2} - 10.236	{3} - 14.169	{4} - 7.1865
1	1	1		0.000010	0.000010	0.988635
2	1	2	0.000010		0.000010	0.000010
3	1	3	0.000010	0.000010		0.000010
4	2	1	0.988635	0.000010	0.000010	
5	2	2	0.552587	0.003302	0.000010	0.076154
6	2	3	0.000010	0.999175	0.000010	0.000010
7	3	1	0.999943	0.000010	0.000010	0.999898

8	3	2	0.579575	0.002839	0.000010	0.084581
9	3	3	0.000010	0.999831	0.000010	0.000010

{5} - 8.5044	**{6} - 10.533**	**{7} - 7.4107**	**{8} - 8.4873**	**{9} - 10.476**
0.552587	0.000010	0.999943	0.579575	0.000010
0.003302	0.999175	0.000010	0.002839	0.999831
0.000010	0.000010	0.000010	0.000010	0.000010
0.076154	0.000010	0.999898	0.084581	0.000010
	0.000215	0.255466	1.000000	0.000360
0.000215		0.000010	0.000185	1.000000
0.255466	0.000010		0.275738	0.000010
1.000000	0.000185	0.275738		0.000308
0.000360	1.000000	0.000010	0.000308	

Extensor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.51053	0.479787
SIZES	2	1.97601	0.146502
MASSES	2	36.62318	0.000000
MATERIAL*SIZES	2	6.18263	0.003412
MATERIAL*MASSES	2	7.29250	0.001351
SIZES*MASSES	4	1.75870	0.140779
MATERIAL*SIZES*MASSES	4	0.83070	0.507849

	MATERIAL	SIZES	MASSES	{1} - 3.6617	{2} - 4.6187	{3} - 5.8565	{4} - 4.0329	{5} - 5.0935	{6} - 4.6343
1	1	1	1		0.587798	0.000039	0.999977	0.031282	0.557145
2	1	1	2	0.587798		0.140849	0.991748	0.999333	1.000000
3	1	1	3	0.000039	0.140849		0.000554	0.899023	0.156213
4	1	2	1	0.999977	0.991748	0.000554		0.388329	0.989035
5	1	2	2	0.031282	0.999333	0.899023	0.388329		0.999567
6	1	2	3	0.557145	1.000000	0.156213	0.989035	0.999567	
7	1	3	1	0.472907	1.000000	0.205037	0.977625	0.999884	1.000000
8	1	3	2	0.000057	0.308395	1.000000	0.002392	0.981447	0.334032
9	1	3	3	0.000036	0.000050	0.775043	0.000036	0.005299	0.000054
10	2	1	1	0.999996	0.982120	0.000335	1.000000	0.312103	0.977149
11	2	1	2	0.087438	0.999991	0.715373	0.633525	1.000000	0.999995
12	2	1	3	0.000036	0.000036	0.019689	0.000036	0.000037	0.000036
13	2	2	1	1.000000	0.813259	0.000056	1.000000	0.086979	0.789390
14	2	2	2	0.223138	1.000000	0.445873	0.863692	1.000000	1.000000
15	2	2	3	0.000036	0.008475	0.999995	0.000041	0.325122	0.009878
16	2	3	1	0.999738	0.998157	0.001237	1.000000	0.523486	0.997361
17	2	3	2	0.445941	1.000000	0.223091	0.972341	0.999928	1.000000
18	2	3	3	0.000036	0.000141	0.943479	0.000036	0.021403	0.000165

	{7} - 4.6772	{8} - 5.7259	{9} - 6.7118	{10} - 3.9886	{11} - 4.9665	{12} - 7.3400
1	0.472907	0.000057	0.000036	0.999996	0.087438	0.000036
2	1.000000	0.308395	0.000050	0.982120	0.999991	0.000036
3	0.205037	1.000000	0.775043	0.000335	0.715373	0.019689
4	0.977625	0.002392	0.000036	1.000000	0.633525	0.000036
5	0.999884	0.981447	0.005299	0.312103	1.000000	0.000037
6	1.000000	0.334032	0.000054	0.977149	0.999995	0.000036
7		0.410064	0.000069	0.957746	0.999999	0.000036
8	0.410064		0.530999	0.001468	0.902718	0.005530
9	0.000069	0.530999		0.000036	0.001345	0.982657

10	0.957746	0.001468	0.000036		0.546563	0.000036
11	0.999999	0.902718	0.001345	0.546563		0.000036
12	0.000036	0.005530	0.982657	0.000036	0.000036	
13	0.716599	0.000158	0.000036	1.000000	0.205890	0.000036
14	1.000000	0.698862	0.000278	0.801928	1.000000	0.000036
15	0.014930	0.999497	0.997858	0.000039	0.154465	0.244435
16	0.993498	0.005096	0.000036	1.000000	0.762770	0.000036
17	1.000000	0.436337	0.000076	0.949294	1.000000	0.000036
18	0.000261	0.796254	1.000000	0.000036	0.006297	0.889287

	{13} - 3.7880	**{14} - 4.8269**	**{15} - 6.1905**	**{16} - 4.1039**	**{17} - 4.6913**	**{18} - 6.5679**
1	1.000000	0.223138	0.000036	0.999738	0.445941	0.000036
2	0.813259	1.000000	0.008475	0.998157	1.000000	0.000141
3	0.000056	0.445873	0.999995	0.001237	0.223091	0.943479
4	1.000000	0.863692	0.000041	1.000000	0.972341	0.000036
5	0.086979	1.000000	0.325122	0.523486	0.999928	0.021403
6	0.789390	1.000000	0.009878	0.997361	1.000000	0.000165
7	0.716599	1.000000	0.014930	0.993498	1.000000	0.000261
8	0.000158	0.698862	0.999497	0.005096	0.436337	0.796254
9	0.000036	0.000278	0.997858	0.000036	0.000076	1.000000
10	1.000000	0.801928	0.000039	1.000000	0.949294	0.000036
11	0.205890	1.000000	0.154465	0.762770	1.000000	0.006297
12	0.000036	0.000036	0.244435	0.000036	0.000036	0.889287
13		0.428265	0.000036	0.999998	0.690967	0.000036
14	0.428265		0.055416	0.934967	1.000000	0.001409
15	0.000036	0.055416		0.000052	0.017033	0.999971
16	0.999998	0.934967	0.000052		0.991497	0.000036
17	0.690967	1.000000	0.017033	0.991497		0.000304
18	0.000036	0.001409	0.999971	0.000036	0.000304	

	Degr. of - Freedom	**F**	**p**
COND	2	1.82184	0.169534
MASSES	2	19.17404	0.0000002
COND*MASSES	4	7.74033	0.000012

	COND	**MASSES**	**{1} - 3.0413**	**{2} - 4.7874**	**{3} - 7.6012**	**{4} - 4.0329**
1	1	1		0.033611	0.000010	0.658553
2	1	2	0.033611		0.000016	0.899656
3	1	3	0.000010	0.000016		0.000010
4	2	1	0.658553	0.899656	0.000010	
5	2	2	0.004617	0.999748	0.000151	0.569573
6	2	3	0.077703	0.999999	0.000011	0.972490

7	3	1	0.904975	0.648677	0.000010	0.999953
8	3	2	0.026608	1.000000	0.000019	0.869871
9	3	3	0.000010	0.187749	0.181835	0.002140

{5} - 5.0935	**{6} - 4.6343**	**{7} - 3.7880**	**{8} - 4.8269**	**{9} - 6.1905**
0.004617	0.077703	0.904975	0.026608	0.000010
0.999748	0.999999	0.648677	1.000000	0.187749
0.000151	0.000011	0.000010	0.000019	0.181835
0.569573	0.972490	0.999953	0.869871	0.002140
	0.995283	0.274867	0.999911	0.522030
0.995283		0.823246	0.999993	0.093487
0.274867	0.823246		0.597812	0.000325
0.999911	0.999993	0.597812		0.220428
0.522030	0.093487	0.000325	0.220428	

Flexor Carpi Ulnaris

	Degr. of - Freedom	F	p
MATERIAL	1	0.3657	0.549379
SIZE	2	1.3013	0.278876
MASS	2	28.9088	0.000000001
MATERIAL*SIZE	2	1.1926	0.309698
MATERIAL*MASS	2	3.7355	0.028892
SIZE*MASS	4	1.9070	0.112769
MATERIAL*SIZE*MASS	4	1.0542	0.381817

	MATERIAL	SIZE	MASS	{1} - 1.6303	{2} - 1.5528	{3} - 2.0277	{4} - 1.5282	{5} - 1.6055	{6} - 1.8505
1	1	1	1		0.999814	0.000038	0.994144	1.000000	0.152578
2	1	1	2	0.999814		0.000036	1.000000	0.999999	0.003529
3	1	1	3	0.000038	0.000036		0.000036	0.000036	0.529845
4	1	2	1	0.994144	1.000000	0.000036		0.999818	0.000777
5	1	2	2	1.000000	0.999999	0.000036	0.999818		0.055405
6	1	2	3	0.152578	0.003529	0.529845	0.000777	0.055405	
7	1	3	1	1.000000	1.000000	0.000036	0.999996	1.000000	0.023759
8	1	3	2	1.000000	1.000000	0.000036	0.999998	1.000000	0.020625
9	1	3	3	0.848111	0.141498	0.038989	0.050872	0.613586	0.999870
10	2	1	1	1.000000	0.995448	0.000051	0.955399	1.000000	0.318245
11	2	1	2	0.999996	0.901911	0.000283	0.702163	0.999461	0.703299
12	2	1	3	0.070731	0.001092	0.733964	0.000233	0.022166	1.000000
13	2	2	1	0.999502	1.000000	0.000036	1.000000	0.999997	0.002473
14	2	2	2	1.000000	0.999996	0.000036	0.999464	1.000000	0.073894
15	2	2	3	0.528582	0.035220	0.153226	0.009981	0.280604	1.000000
16	2	3	1	1.000000	0.998681	0.000043	0.979682	1.000000	0.235869
17	2	3	2	0.985594	0.411165	0.006707	0.197777	0.907168	0.987524
18	2	3	3	0.194346	0.005259	0.456203	0.001191	0.074591	1.000000

	{7} - 1.5877	{8} - 1.5849	{9} - 1.7751	{10} - 1.6527	{11} - 1.6894	{12} - 1.8697
1	1.000000	1.000000	0.848111	1.000000	0.999996	0.070731
2	1.000000	1.000000	0.141498	0.995448	0.901911	0.001092
3	0.000036	0.000036	0.038989	0.000051	0.000283	0.733964
4	0.999996	0.999998	0.050872	0.955399	0.702163	0.000233
5	1.000000	1.000000	0.613586	1.000000	0.999461	0.022166
6	0.023759	0.020625	0.999870	0.318245	0.703299	1.000000
7		1.000000	0.420427	0.999984	0.994356	0.008642
8	1.000000		0.391695	0.999971	0.992348	0.007397
9	0.420427	0.391695		0.961658	0.999294	0.997578
10	0.999984	0.999971	0.961658		1.000000	0.171264

11	0.994356	0.992348	0.999294	1.000000		0.496219
12	0.008642	0.007397	0.997578	0.171264	0.496219	
13	1.000000	1.000000	0.112514	0.991278	0.864513	0.000751
14	1.000000	1.000000	0.683562	1.000000	0.999817	0.030698
15	0.154278	0.138999	1.000000	0.763242	0.972536	0.999992
16	0.999999	0.999997	0.924466	1.000000	1.000000	0.118680
17	0.776860	0.750836	1.000000	0.998939	0.999999	0.940480
18	0.033166	0.028950	0.999965	0.383350	0.769180	1.000000

	{13} - 1.5469	{14} - 1.6121	{15} - 1.8076	{16} - 1.6429	{17} - 1.7411	{18} - 1.8437
1	0.999502	1.000000	0.528582	1.000000	0.985594	0.194346
2	1.000000	0.999996	0.035220	0.998681	0.411165	0.005259
3	0.000036	0.000036	0.153226	0.000043	0.006707	0.456203
4	1.000000	0.999464	0.009981	0.979682	0.197777	0.001191
5	0.999997	1.000000	0.280604	1.000000	0.907168	0.074591
6	0.002473	0.073894	1.000000	0.235869	0.987524	1.000000
7	1.000000	1.000000	0.154278	0.999999	0.776860	0.033166
8	1.000000	1.000000	0.138999	0.999997	0.750836	0.028950
9	0.112514	0.683562	1.000000	0.924466	1.000000	0.999965
10	0.991278	1.000000	0.763242	1.000000	0.998939	0.383350
11	0.864513	0.999817	0.972536	1.000000	0.999999	0.769180
12	0.000751	0.030698	0.999992	0.118680	0.940480	1.000000
13		0.999983	0.026378	0.997128	0.351804	0.003708
14	0.999983		0.339674	1.000000	0.938496	0.098100
15	0.026378	0.339674		0.665376	0.999978	1.000000
16	0.997128	1.000000	0.665376		0.996204	0.291331
17	0.351804	0.938496	0.999978	0.996204		0.993805
18	0.003708	0.098100	1.000000	0.291331	0.993805	

	Degr. of - Freedom	F	p
COND	2	1.9432	0.151110
MASS	2	37.3224	0.00000000001
COND*MASS	4	9.7224	0.000001

	COND	MASS	{1} - 1.4177	{2} - 1.6616	{3} - 2.3073	{4} - 1.5282
1	1	1		0.064923	0.000010	0.910992
2	1	2	0.064923		0.000010	0.778477
3	1	3	0.000010	0.000010		0.000010
4	2	1	0.910992	0.778477	0.000010	
5	2	2	0.330041	0.998891	0.000010	0.989659
6	2	3	0.000013	0.321836	0.000011	0.002249
7	3	1	0.807676	0.891836	0.000010	1.000000

8	3	2	0.283287	0.999555	0.000010	0.982443
9	3	3	0.000059	0.679896	0.000010	0.016336

{5} - 1.6055	**{6} - 1.8505**	**{7} - 1.5469**	**{8} - 1.6121**	**{9} - 1.8076**
0.330041	0.000013	0.807676	0.283287	0.000059
0.998891	0.321836	0.891836	0.999555	0.679896
0.000010	0.000011	0.000010	0.000010	0.000010
0.989659	0.002249	1.000000	0.982443	0.016336
	0.062415	0.998471	1.000000	0.233609
0.062415		0.005545	0.078431	0.999848
0.998471	0.005545		0.996754	0.034813
1.000000	0.078431	0.996754		0.275501
0.233609	0.999848	0.034813	0.275501	

Flexor Carpi Radialis

	Degr. of - Freedom	F	p
MATERIAL	1	0.0212	0.885188
SIZE	2	3.5992	0.032675
MASS	2	29.8151	0.000000001
MATERIAL*SIZE	2	0.6104	0.546074
MATERIAL*MASS	2	0.3145	0.731196
SIZE*MASS	4	3.1217	0.017104
MATERIAL*SIZE*MASS	4	1.3547	0.253026

	MATERIAL	SIZE	MAS	{1} - 2.6556	{2} - 3.1563	{3} - 4.2765	{4} - 2.6707	{5} - 3.1414	{6} - 3.8311
1	1	1	1		0.625124	0.000036	1.000000	0.678520	0.000039
2	1	1	2	0.625124		0.000049	0.679365	1.000000	0.117644
3	1	1	3	0.000036	0.000049		0.000036	0.000045	0.808016
4	1	2	1	1.000000	0.679365	0.000036		0.730233	0.000040
5	1	2	2	0.678520	1.000000	0.000045	0.730233		0.096260
6	1	2	3	0.000039	0.117644	0.808016	0.000040	0.096260	
7	1	3	1	0.000041	0.149664	0.751294	0.000043	0.123762	1.000000
8	1	3	2	0.011368	0.988552	0.017812	0.014913	0.981651	0.971629
9	1	3	3	0.000036	0.000036	0.025514	0.000036	0.000036	0.000037
10	2	1	1	0.989657	0.999994	0.000036	0.993950	0.999998	0.006146
11	2	1	2	0.451282	1.000000	0.000082	0.506312	1.000000	0.210319
12	2	1	3	0.000036	0.000474	1.000000	0.000036	0.000346	0.993495
13	2	2	1	0.999998	0.983582	0.000036	1.000000	0.989868	0.000266
14	2	2	2	0.283793	1.000000	0.000204	0.329409	1.000000	0.355568
15	2	2	3	0.000055	0.267849	0.572436	0.000065	0.228325	1.000000
16	2	3	1	0.134987	0.999999	0.000792	0.163084	0.999995	0.586252
17	2	3	2	0.043413	0.999612	0.004092	0.054808	0.999162	0.844849
18	2	3	3	0.000036	0.000036	0.049717	0.000036	0.000036	0.000038

	{7} - 3.8123	{8} - 3.4787	{9} - 5.0532	{10} - 2.9749	{11} - 3.2037	{12} - 4.1372
1	0.000041	0.011368	0.000036	0.989657	0.451282	0.000036
2	0.149664	0.988552	0.000036	0.999994	1.000000	0.000474
3	0.751294	0.017812	0.025514	0.000036	0.000082	1.000000
4	0.000043	0.014913	0.000036	0.993950	0.506312	0.000036
5	0.123762	0.981651	0.000036	0.999998	1.000000	0.000346
6	1.000000	0.971629	0.000037	0.006146	0.210319	0.993495
7		0.983587	0.000036	0.008747	0.258247	0.987547
8	0.983587		0.000036	0.614055	0.998153	0.144948
9	0.000036	0.000036		0.000036	0.000036	0.001864
10	0.008747	0.614055	0.000036		0.999827	0.000040

11	0.258247	0.998153	0.000036	0.999827		0.001296
12	0.987547	0.144948	0.001864	0.000040	0.001296	
13	0.000394	0.149648	0.000036	1.000000	0.941828	0.000036
14	0.419045	0.999873	0.000036	0.997684	1.000000	0.003696
15	1.000000	0.997413	0.000036	0.021637	0.417808	0.948474
16	0.654668	0.999999	0.000036	0.977066	1.000000	0.012582
17	0.888000	1.000000	0.000036	0.862104	0.999981	0.047735
18	0.000037	0.000036	1.000000	0.000036	0.000036	0.004311

	{13} - 2.8227	{14} - 3.2550	{15} - 3.7614	{16} - 3.3197	{17} - 3.3994	{18} - 5.0116
1	0.999998	0.283793	0.000055	0.134987	0.043413	0.000036
2	0.983582	1.000000	0.267849	0.999999	0.999612	0.000036
3	0.000036	0.000204	0.572436	0.000792	0.004092	0.049717
4	1.000000	0.329409	0.000065	0.163084	0.054808	0.000036
5	0.989868	1.000000	0.228325	0.999995	0.999162	0.000036
6	0.000266	0.355568	1.000000	0.586252	0.844849	0.000038
7	0.000394	0.419045	1.000000	0.654668	0.888000	0.000037
8	0.149648	0.999873	0.997413	0.999999	1.000000	0.000036
9	0.000036	0.000036	0.000036	0.000036	0.000036	1.000000
10	1.000000	0.997684	0.021637	0.977066	0.862104	0.000036
11	0.941828	1.000000	0.417808	1.000000	0.999981	0.000036
12	0.000036	0.003696	0.948474	0.012582	0.047735	0.004311
13		0.843164	0.001162	0.638628	0.353402	0.000036
14	0.843164		0.604553	1.000000	1.000000	0.000036
15	0.001162	0.604553		0.818451	0.963433	0.000036
16	0.638628	1.000000	0.818451		1.000000	0.000036
17	0.353402	1.000000	0.963433	1.000000		0.000036
18	0.000036	0.000036	0.000036	0.000036	0.000036	

	Degr. of - Freedom	F	p
COND	2	0.52389	0.594585
MASS	2	21.81327	0.00000005
COND*MASS	4	6.97451	0.000039

	COND	MASS	{1} - 2.4654	{2} - 3.1254	{3} - 4.5413	{4} - 2.6707
1	1	1		0.003541	0.000010	0.956071
2	1	2	0.003541		0.000010	0.161115
3	1	3	0.000010	0.000010		0.000010
4	2	1	0.956071	0.161115	0.000010	
5	2	2	0.002440	1.000000	0.000010	0.128314
6	2	3	0.000010	0.001199	0.001076	0.000010

7	3	1	0.477770	0.700237	0.000010	0.993524
8	3	2	0.000160	0.997850	0.000010	0.017982
9	3	3	0.000010	0.006072	0.000199	0.000010

{5} - 3.1414	{6} - 3.8311	{7} - 2.8227	{8} - 3.2550	{9} - 3.7614
0.002440	0.000010	0.477770	0.000160	0.000010
1.000000	0.001199	0.700237	0.997850	0.006072
0.000010	0.001076	0.000010	0.000010	0.000199
0.128314	0.000010	0.993524	0.017982	0.000010
	0.001766	0.636690	0.999170	0.008603
0.001766		0.000010	0.021129	0.999979
0.636690	0.000010		0.216257	0.000011
0.999170	0.021129	0.216257		0.073854
0.008603	0.999979	0.000011	0.073854	

F1 pressure (N)

	Degr. of - Freedom	F	p
MATERIAL	1	5.00266	0.031975
SIZES	2	0.96450	0.386328
MASSES	2	12.82654	0.000019
MATERIAL*SIZES	2	1.34614	0.267089
MATERIAL*MASSES	2	2.11612	0.128365
SIZES*MASSES	4	1.47261	0.213910
MATERIAL*SIZES*MASSES	4	3.34677	0.011974

	MATERIAL	SIZES	MASSES	{1} - 2.9492	{2} - 4.3911	{3} - 5.8316	{4} - 2.3995	{5} - 3.4127	{6} - 3.6805
1	1	1	1		0.997911	0.426328	1.000000	1.000000	1.000000
2	1	1	2	0.997911		0.997934	0.938325	0.999989	1.000000
3	1	1	3	0.426328	0.997934		0.140323	0.745700	0.884865
4	1	2	1	1.000000	0.938325	0.140323		0.999981	0.999529
5	1	2	2	1.000000	0.999989	0.745700	0.999981		1.000000
6	1	2	3	1.000000	1.000000	0.884865	0.999529	1.000000	
7	1	3	1	1.000000	0.921156	0.121257	1.000000	0.999958	0.999159
8	1	3	2	0.979140	1.000000	0.999933	0.802112	0.999371	0.999972
9	1	3	3	0.353674	0.995030	1.000000	0.106042	0.673048	0.834156
10	2	1	1	1.000000	0.999837	0.608543	0.999999	1.000000	1.000000
11	2	1	2	1.000000	0.999995	0.776528	0.999963	1.000000	1.000000
12	2	1	3	0.203939	0.971697	1.000000	0.049086	0.477931	0.666675
13	2	2	1	0.998672	1.000000	0.996834	0.951183	0.999995	1.000000
14	2	2	2	0.348831	0.994739	1.000000	0.103922	0.667759	0.830214
15	2	2	3	0.011571	0.464843	0.998717	0.001453	0.051468	0.107897
16	2	3	1	0.000140	0.031897	0.678898	0.000042	0.000883	0.002583
17	2	3	2	0.086685	0.873678	1.000000	0.016231	0.259843	0.422226
18	2	3	3	0.254165	0.984230	1.000000	0.066278	0.551415	0.735084

	{7} - 2.3406	{8} - 4.7225	{9} - 5.9430	{10} - 3.2084	{11} - 3.4637	{12} - 6.2201
1	1.000000	0.979140	0.353674	1.000000	1.000000	0.203939
2	0.921156	1.000000	0.995030	0.999837	0.999995	0.971697
3	0.121257	0.999933	1.000000	0.608543	0.776528	1.000000
4	1.000000	0.802112	0.106042	0.999999	0.999963	0.049086
5	0.999958	0.999371	0.673048	1.000000	1.000000	0.477931
6	0.999159	0.999972	0.834156	1.000000	1.000000	0.666675
7		0.768197	0.090802	0.999998	0.999920	0.041143
8	0.768197		0.999752	0.996261	0.999625	0.996713
9	0.090802	0.999752		0.529379	0.707103	1.000000
10	0.999998	0.996261	0.529379		1.000000	0.342486

11	0.999920	0.999625	0.707103	1.000000		0.513866
12	0.041143	0.996713	1.000000	0.342486	0.513866	
13	0.936541	1.000000	0.992778	0.999913	0.999998	0.963001
14	0.088931	0.999730	1.000000	0.523854	0.701990	1.000000
15	0.001145	0.696891	0.999560	0.027515	0.059690	0.999985
16	0.000040	0.084146	0.751043	0.000382	0.001087	0.892023
17	0.013276	0.969010	1.000000	0.166429	0.287524	1.000000
18	0.055985	0.998621	1.000000	0.409127	0.587707	1.000000

	{13} - 4.3388	{14} - 5.9507	{15} - 7.2173	{16} - 8.3532	{17} - 6.5689	{18} - 6.1163
1	0.998672	0.348831	0.011571	0.000140	0.086685	0.254165
2	1.000000	0.994739	0.464843	0.031897	0.873678	0.984230
3	0.996834	1.000000	0.998717	0.678898	1.000000	1.000000
4	0.951183	0.103922	0.001453	0.000042	0.016231	0.066278
5	0.999995	0.667759	0.051468	0.000883	0.259843	0.551415
6	1.000000	0.830214	0.107897	0.002583	0.422226	0.735084
7	0.936541	0.088931	0.001145	0.000040	0.013276	0.055985
8	1.000000	0.999730	0.696891	0.084146	0.969010	0.998621
9	0.992778	1.000000	0.999560	0.751043	1.000000	1.000000
10	0.999913	0.523854	0.027515	0.000382	0.166429	0.409127
11	0.999998	0.701990	0.059690	0.001087	0.287524	0.587707
12	0.963001	1.000000	0.999985	0.892023	1.000000	1.000000
13		0.992380	0.428921	0.027033	0.849980	0.978630
14	0.992380		0.999594	0.755811	1.000000	1.000000
15	0.428921	0.999594		0.999906	1.000000	0.999939
16	0.027033	0.755811	0.999906		0.977810	0.846765
17	0.849980	1.000000	1.000000	0.977810		1.000000
18	0.978630	1.000000	0.999939	0.846765	1.000000	

	Degr. of - Freedom	F	p
COND	2	2.23081	0.115247
MASS	2	17.49734	0.000001
COND*MASS	4	1.44089	0.223857

	COND	MASS	{1} - 1.6382	{2} - 3.4125	{3} - 5.5086	{4} - 2.3995
1	1	1		0.377730	0.000044	0.989112
2	1	2	0.377730		0.166377	0.937207
3	1	3	0.000044	0.166377		0.002755
4	2	1	0.989112	0.937207	0.002755	
5	2	2	0.377589	1.000000	0.166462	0.937147
6	2	3	0.194256	0.999995	0.335383	0.794527
7	3	1	0.018549	0.962615	0.865748	0.256230

8	3	2	0.000012	0.036130	0.999772	0.000273
9	3	3	0.000010	0.000061	0.432285	0.000010

{5} - 3.4127	**{6} - 3.6805**	**{7} - 4.3388**	**{8} - 5.9507**	**{9} - 7.2173**
0.377589	0.194256	0.018549	0.000012	0.000010
1.000000	0.999995	0.962615	0.036130	0.000061
0.166462	0.335383	0.865748	0.999772	0.432285
0.937147	0.794527	0.256230	0.000273	0.000010
	0.999995	0.962657	0.036155	0.000061
0.999995		0.995924	0.096106	0.000294
0.962657	0.995924		0.516804	0.008397
0.036155	0.096106	0.516804		0.804697
0.000061	0.000294	0.008397	0.804697	

F2 pressure (N)

	Degr. of - Freedom	F	p
MATERIAL	1	0.00817	0.928502
SIZE	2	0.39719	0.673755
MASS	2	8.42131	0.000540
MATERIAL*SIZE	2	0.48836	0.615767
MATERIAL*MASS	2	1.88073	0.160324
SIZE*MASS	4	0.82773	0.509698
MATERIAL*SIZE*MASS	4	0.89819	0.467008

	MATERIAL	SIZE	MASS	{1} - 3.6559	{2} - 6.8929	{3} - 9.1103	{4} - 6.3719	{5} - 6.5033	{6} - 10.174
1	1	1	1		0.999300	0.852173	0.999934	0.999872	0.582848
2	1	1	2	0.999300		0.999996	1.000000	1.000000	0.999169
3	1	1	3	0.852173	0.999996		0.999926	0.999963	1.000000
4	1	2	1	0.999934	1.000000	0.999926		1.000000	0.995053
5	1	2	2	0.999872	1.000000	0.999963	1.000000		0.996712
6	1	2	3	0.582848	0.999169	1.000000	0.995053	0.996712	
7	1	3	1	0.872351	0.999998	1.000000	0.999958	0.999980	1.000000
8	1	3	2	0.999996	1.000000	0.999376	1.000000	1.000000	0.982486
9	1	3	3	0.851651	0.999996	1.000000	0.999925	0.999962	1.000000
10	2	1	1	1.000000	0.999990	0.963986	1.000000	0.999999	0.809320
11	2	1	2	0.921091	1.000000	1.000000	0.999994	0.999997	1.000000
12	2	1	3	0.334471	0.986136	0.999999	0.956088	0.966252	1.000000
13	2	2	1	1.000000	0.939430	0.419719	0.978960	0.971791	0.180213
14	2	2	2	0.999999	1.000000	0.998650	1.000000	1.000000	0.972254
15	2	2	3	0.997309	1.000000	1.000000	1.000000	1.000000	0.999829
16	2	3	1	1.000000	0.999995	0.970925	1.000000	1.000000	0.831291
17	2	3	2	0.999005	1.000000	0.999998	1.000000	1.000000	0.999420
18	2	3	3	0.008003	0.318560	0.886660	0.207062	0.232352	0.985384

	{7} - 9.0010	{8} - 5.9021	{9} - 9.1130	{10} - 4.5127	{11} - 8.6818	{12} - 11.069
1	0.872351	0.999996	0.851651	1.000000	0.921091	0.334471
2	0.999998	1.000000	0.999996	0.999990	1.000000	0.986136
3	1.000000	0.999376	1.000000	0.963986	1.000000	0.999999
4	0.999958	1.000000	0.999925	1.000000	0.999994	0.956088
5	0.999980	1.000000	0.999962	0.999999	0.999997	0.966252
6	1.000000	0.982486	1.000000	0.809320	1.000000	1.000000
7		0.999603	1.000000	0.971355	1.000000	0.999999
8	0.999603		0.999370	1.000000	0.999908	0.901389
9	1.000000	0.999370		0.963787	1.000000	0.999999
10	0.971355	1.000000	0.963787		0.986384	0.571617

11	1.000000	0.999908	1.000000	0.986384		0.999990
12	0.999999	0.901389	0.999999	0.571617	0.999990	
13	0.450092	0.993770	0.418976	0.999981	0.541669	0.071176
14	0.999103	1.000000	0.998637	1.000000	0.999762	0.868085
15	1.000000	1.000000	1.000000	0.999920	1.000000	0.995014
16	0.977149	1.000000	0.970756	1.000000	0.989547	0.601276
17	0.999999	1.000000	0.999998	0.999983	1.000000	0.989016
18	0.867845	0.132448	0.887103	0.026339	0.802987	0.999099

	{13} - 2.0221	**{14} - 5.7003**	**{15} - 7.2648**	**{16} - 4.6150**	**{17} - 6.9837**	**{18} - 14.371**
1	1.000000	0.999999	0.997309	1.000000	0.999005	0.008003
2	0.939430	1.000000	1.000000	0.999995	1.000000	0.318560
3	0.419719	0.998650	1.000000	0.970925	0.999998	0.886660
4	0.978960	1.000000	1.000000	1.000000	1.000000	0.207062
5	0.971791	1.000000	1.000000	1.000000	1.000000	0.232352
6	0.180213	0.972254	0.999829	0.831291	0.999420	0.985384
7	0.450092	0.999103	1.000000	0.977149	0.999999	0.867845
8	0.993770	1.000000	1.000000	1.000000	1.000000	0.132448
9	0.418976	0.998637	1.000000	0.970756	0.999998	0.887103
10	0.999981	1.000000	0.999920	1.000000	0.999983	0.026339
11	0.541669	0.999762	1.000000	0.989547	1.000000	0.802987
12	0.071176	0.868085	0.995014	0.601276	0.989016	0.999099
13		0.996630	0.889645	0.999966	0.929109	0.000590
14	0.996630		1.000000	1.000000	1.000000	0.107555
15	0.889645	1.000000		0.999953	1.000000	0.414690
16	0.999966	1.000000	0.999953		0.999991	0.030079
17	0.929109	1.000000	1.000000	0.999991		0.340912
18	0.000590	0.107555	0.414690	0.030079	0.340912	

	Degr. of - Freedom	**F**	**p**
COND	2	0.43096	0.651647
MASS	2	6.24295	0.003242
COND*MASS	4	1.37275	0.246640

Electromyography printout

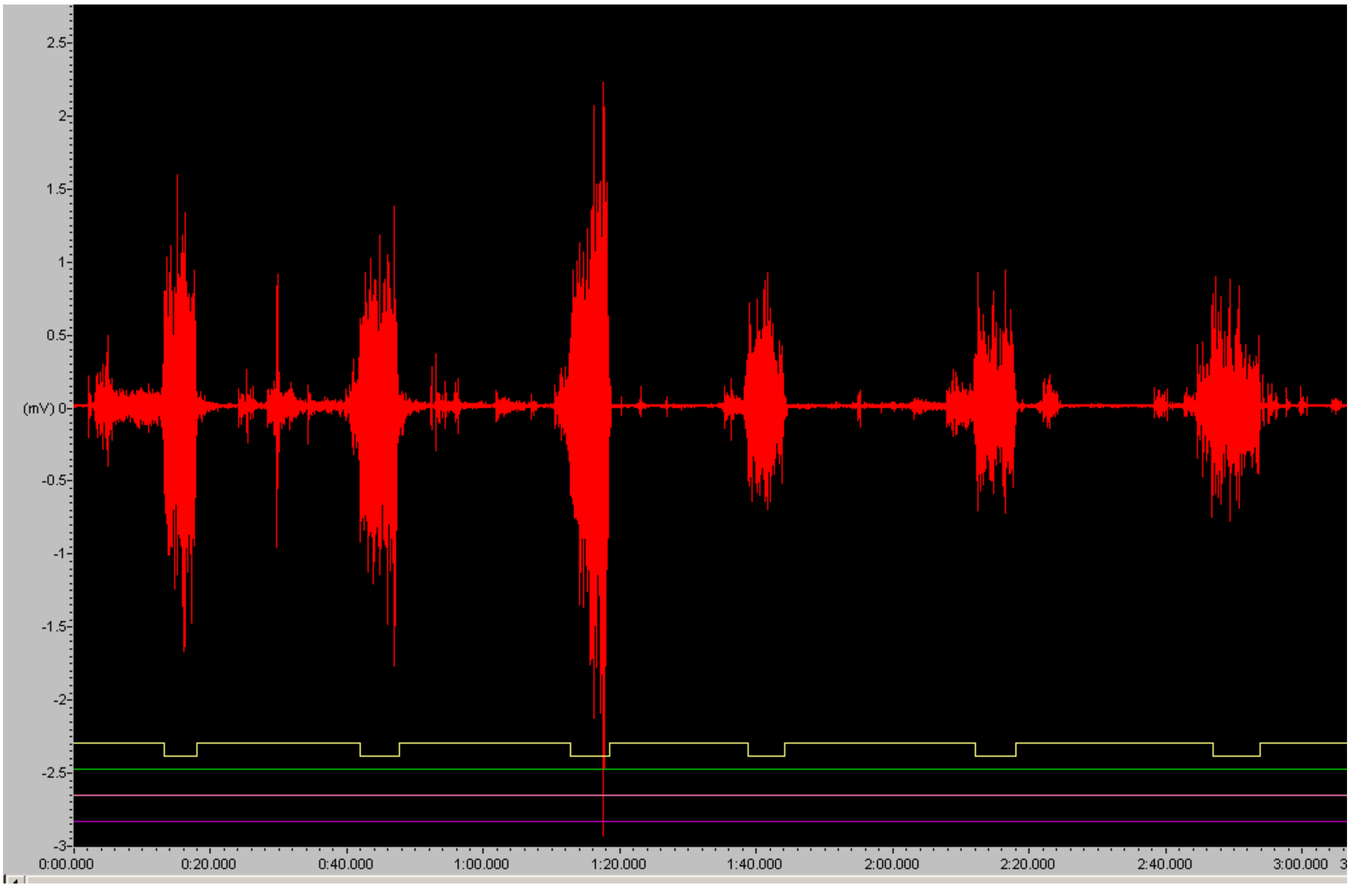
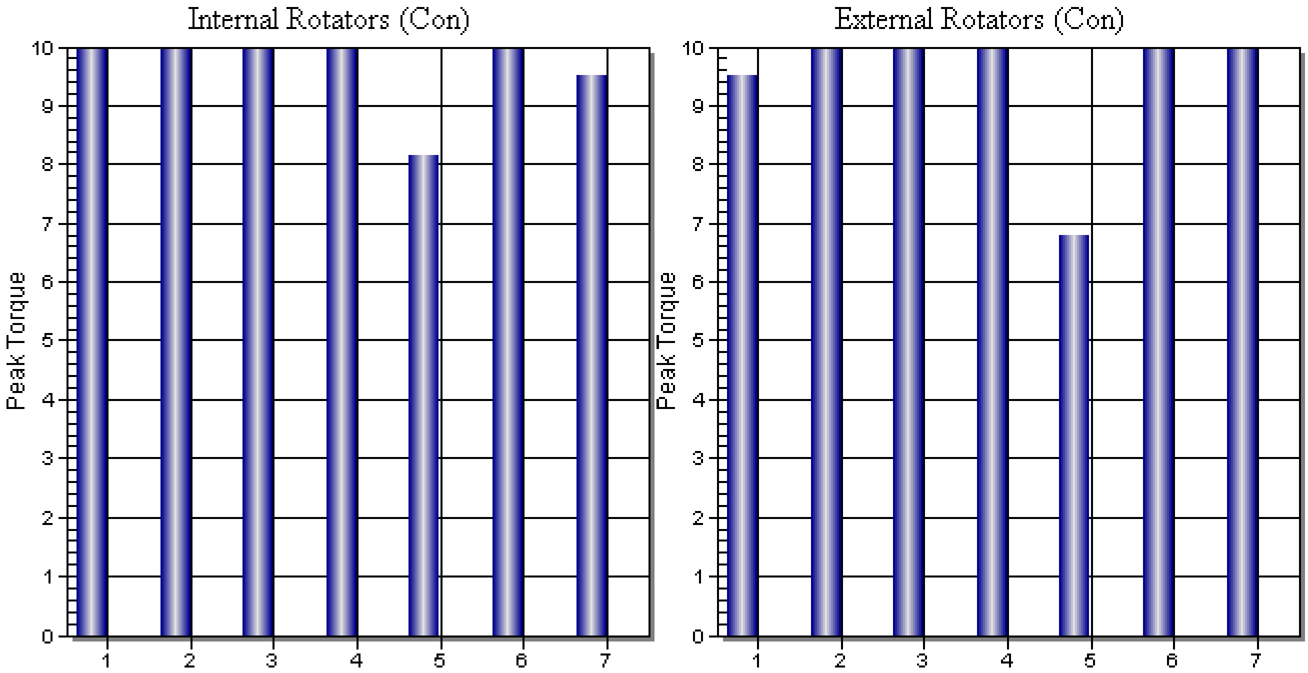


Figure 38: An example of an EMG recording of the Flexor Digitorum Superficialis muscle during the maximum pushing task.

Cybex torque test printout



Right Side Curves Left Side Curves

	Internal Rotators (Con)			External Rotators (Con)		
	Right	Left	Deficit	Right	Left	Deficit
Speed 60/60 deg/sec 3 Reps	11	0	0	9	0	0
Speed 60/60 deg/sec 3 Reps	14	0	0	12	0	0
Speed 60/60 deg/sec 3 Reps	14	0	0	11	0	0
Speed 60/60 deg/sec 3 Reps	12	0	0	11	0	0
Speed 60/60 deg/sec 3 Reps	8	0	0	7	0	0
Speed 60/60 deg/sec 3 Reps	11	0	0	11	0	0
Speed 60/60 deg/sec 3 Reps	9	0	0	12	0	0

Figure 39: An example of peak torque results for the barehanded and six gloved conditions from the Cybex.